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DEFENSE COMMUNICATIONS ENGINEERING CENTER

ENGINEERING PUBLICATION NO. 27-77

DESIGN OBJECTIVES FOR DCS LOS DIGITAL RADIO LINKS

DECEMBER 1977

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DESIGN OBJECTIVES FOR

DCS LOS DIGITAL RADIO LINKS

DECEMBER 1977

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FOREWORD

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Victor Weill is also acknowledged for his critical editorial review and suggestions, resulting in a much more organized format, which should enhance the understanding and application of the design methodology. The fine typing expertise of Lynn Mentzer is also recognized.

SUMMARY

This Engineering Publication defines system design objectives for designing new or upgrading existing line-of-sight (LOS) digital radio links in the Defense Communications System (DCS). The four major system design parameters treated in this publication are:

a. Digital Performance Threshold

b. System Availability Criteria

c. Path Clearance Criteria

d. Fade Margin Criteria.

Appendixes A and B contain detailed methodology with step-by-step procedures whereby LOS digital radio links can be engineered to meet the performance requirements defined and developed in DCEC TR 12-76. Appendix C contains two examples illustrating the use of the detailed methodology developed in Appendixes A and B. Appendix D presents a simplified procedure for determining required link margin and antenna size for DCS LOS digital links through the use of nomographs.

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I. INTRODUCTION

The primary purpose of this engineering publication is to provide system performance criteria and a methodology for designing LOS digital radio links for the Defense Communications System. Examination of the most pertinent system parameters, from a user's point of view, has necessitated the redefinition of channel performance for voice and data subscribers. The new measures of channel performance, as defined in DCEC TR 12-76 [1], are, for the voice user, "probability of occurrence of a fade outage during a basic five minute call," and for the data user, "error free block probability for a 1000 bit block." These characteristics are presented in Table I, and described in some detail below.

VOICE CRITERION

a. Type I. These outages are of a duration less than 200 milliseconds and, if not too frequent, are considered to have trivial impact. Such outages are barely noticeable to the user. However, tropo links are disturbed by these short fade outage durations.

b. Type II. This outage category occurs over the duration range of 0.2 to 5.0 seconds. The user will experience some annoyance but can continue to communicate.

c. Type III. This outage is defined as lasting more than 5 but no more than 60 seconds. This outage duration could be very disturbing to a user, and may exceed his patience limit, probably causing

TABLE I. SALIENT DCS PERFORMANCE CRITERIA

VOICE CRITERIA

OUTAGE TYPE	APPLICABLE MEDIA	CRITERIA	FADE OUTAGE PROBABILITY PER CALL MINUTE: 12000 MILE GLOBAL REFERENCE CKT.	FADE OUTAGE PROBABILITY PER CALL MINUTE: 600 MILE REF VF OR DATA CKT.	DEPENDENT SYSTEM PARAMETERS
I(3)	Tropo	FOD(1) < 200 m. sec.	not specified (NS) (trivial)	NS	SHORT TERM PHENOMENON
II(3)	LOS & Tropo	200 m sec. < FOD < 5 sec.	0.02	0.0025(5)	FADE MARGIN DIVERSITY TECHNIQUE
III(3)	LOS	5 sec. ≤ FOD < 60 sec.	0.002	0.00025(5)	MTBFO(6)
IV(3)	Tropo	for any FOD 2/min. < FOR(2) < 5/min.	0.01	0.0025(5)(7)	AVERAGE BER THRESHOLD 10^{-4}
			PROBABILITY THE SYSTEM IS UNAVAILABLE		LONG TERM PHENOMENON
V(4)	LOS & Tropo	1/min. < FOD or 5/min. < FOR	0.01 TOTAL a. 0.004 CONUS Terrestrial b. 0.002 Satellite (2) c. 0.004 OCONUS Terrestrial	0.001 TOTAL a. 0.0001 14 LOS hops b. 0.0001 1 Tropo hop c. 0.0008 Equipment	Path Clearance, Equipment Reliability(6) MTTR, MTSR, MTBO AVERAGE BER THRESHOLD 10^{-6}

DATA CRITERIA

VI	LOS & Tropo	ERROR FREE BLOCK PROBABILITY (1000 Bit Block)	.99	.99937	

NOTES
1 Fade Outage Duration
2 Fade Outage Rate
3 These are signal quality criteria (short term phenomenon).
4 This is a system unavailability criteria (long term phenomenon).
5 There are eight 600 mile circuits in the 12,000 mile global reference circuit.
6 MTBFO mean time between fade outage - MTTR mean time to repair - MTSR mean time to service restoral - MTBO mean time between outage (equipment failure and long term media outage)
7 *Considering no tropo in CONUS*

the call to be abandoned. The probability of occurrence of this outage type should be made considerably less than for the Type II.

d. Type IV. This outage type is characteristic of tropo propagation media and is characterized as having a fade outage rate (FOR) of between 2 fade outages per minute and 5 fade outages per minute for any fade outage duration (FOD). The details of this outage type is not treated in this EP but will be covered in an EP which is in preparation.

e. Type V. Outages with duration greater than 1 minute or outages of any duration which occur more frequently than 5 per minute are included in the total link unavailability specification. The channel is considered essentially unusable.

DATA CRITERION

Type VI. This outage type is a data user criterion and is the probability for an error-free 1000 bit block.

Reference [1] contains more details on these different outage types.

Two broad effects can be described when applying the outage characteristics described above to typical LOS link design. The first effect, which is the short term effect, can be perceived as a disturbance to the channel; communications will continue, even though the disturbance may be annoying to the user. These disturbances are characterized by outage Types II, III, and VI, with the latter having an effect on throughput. Type I outages are associated with Tropo Propagation and are very short duration, which are trivial and will not be treated in this EP. These effects can be controlled by

providing sufficient fade margin on the radio system. An analysis of these three types of outages reveals that controlling the Type III outage requires the greatest fade margin. Therefore, the radio link must be designed with sufficient fade margin to avoid or minimize this class of outage. The methodology presented in Appendixes A and B of this EP was developed to satisfy the Type III fade outage criteria.

The second effect, which is a long term effect, is treated with some detail in reference [1] and in this EP. This outage is Type V in which the system or link is considered unusable for communication. Type V is the result of the path clearance, equipment reliability, logistic support, and maintenance concepts employed. Path clearance is treated in this EP but references [7] and [8] can be consulted for further discussion on the other availability effects and how they are implemented into link design.

After considering the types of outages which digital communications systems are apt to experience, the need to define and specify radio link design parameters is evident. This EP treats the following four major system design criteria:

a. Digital Performance Threshold

b. Availability

c. Path Clearance

d. Fade Margin.

Based on material presented in reference [1], a methodology is developed in Appendixes A and B by which LOS digital links can be

designed to meet the operational design goals for the DCS. Appendix C contains two examples illustrating the use of the detailed methodology. Appendix D presents a simplified procedure for determining required fade margin and antenna size for DCS LOS digital links through the use of nomographs.

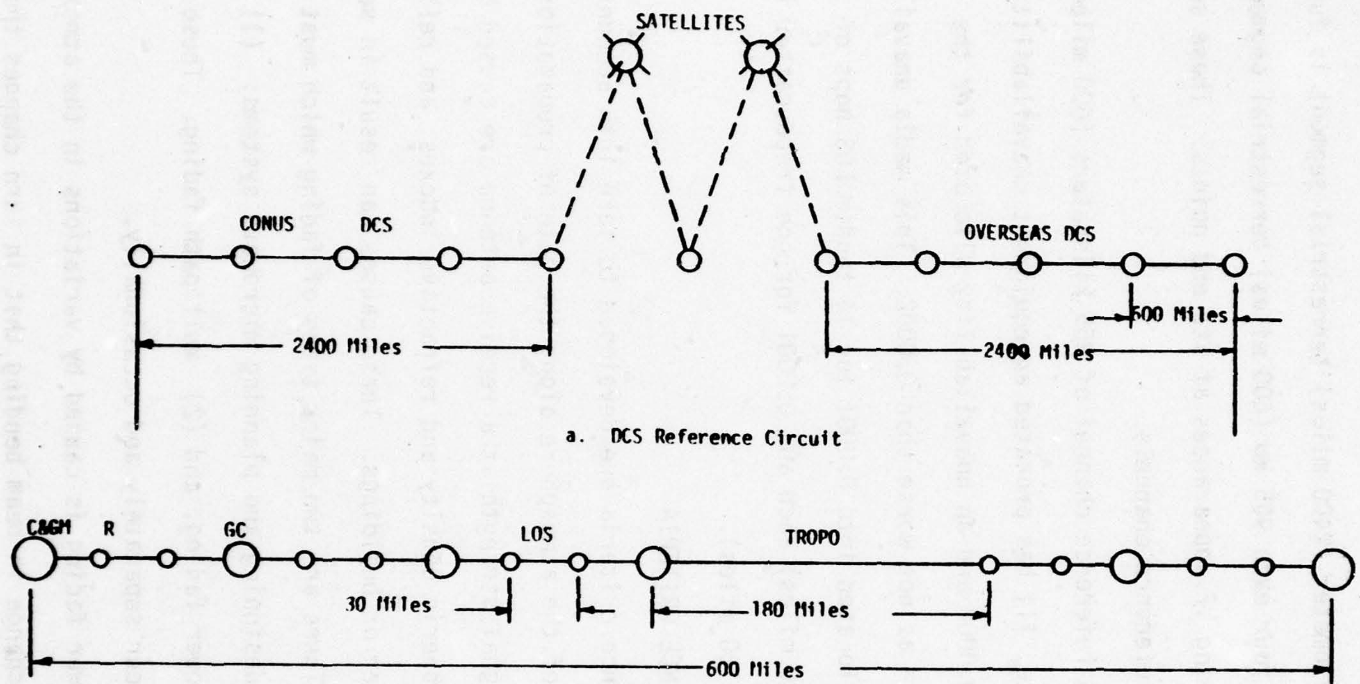
II. LOS DIGITAL RADIO LINK DESIGN OBJECTIVES

1. DIGITAL PERFORMANCE THRESHOLD

The primary measure of transmission quality for a digital system is its bit error performance. Such a measure is valid for systems which regenerate the digital signal at each repeater, since errors, rather than noise and distortion, will accumulate through tandem digital sections. The digital performance threshold is defined as the value of received signal level (RSL) corresponding to a bit error probability of 10^{-4} under non-fading conditions, which has been demonstrated as the maximum acceptable bit error rate for PCM systems.

2. SYSTEM AVAILABILITY CRITERIA

The DCS end-to-end availability requirement of 0.99 has been allocated to the various segments of the global reference circuit as described in reference [1], and Figure 1. The global reference circuit consists of four segments: a leased, common carrier segment of 3860 kilometers (2400 statute miles) spanning CONUS; two satellite segments of one hop each; and an overseas terrestrial segment of government-owned LOS and troposcatter microwave facilities 3860 kilometers (2400 miles) in length. Unavailability, (1 - availability), is defined as that portion of time when the circuit is experiencing long term outages, caused by either anomalous propagation media outages or equipment outages. A link is considered unavailable when it is operating below the digital performance threshold specified in



a. DCS Reference Circuit

b. DCS Reference Channel

Figure 1. DCS Reference Configurations (DCEC TR 12-76)

C&GM--Channel and Group Multiplex
GC----Group Connect
R-----Repeater

paragraph II.1 for an extended period of time.

The 3860 kilometer (2400 miles) terrestrial segment is further subdivided into four each 965 km (600 miles) terrestrial segments, each segment having VF appearances at its end points. These segments are termed DCS reference channels.

For the DCS reference channel of 965 kilometers (600 miles) in length, reference [1] has prorated an equipment unavailability of not worse than 0.0008 and an unavailability allocated for the propagation media as not worse than 0.0002. This media unavailability is further suballocated into 0.0001 for 14 tandem LOS hops of 48 kilometers (30 miles) each and 0.0001 for one troposcatter hop of 290 kilometers (180 miles).

3. PATH CLEARANCE CRITERIA

Path clearance criteria are developed to take into account characteristics of the atmosphere along the path of propagation. The variations in signal strength at a receive antenna are caused by changes in atmospheric density and refractive indexes, and reflections from ground, water or buildings. These causes can result in severe signal fading. There are two major types of fading which must be considered when designing and planning microwave systems: (1) attenuation or power fading, and (2) multipath fading. These types of fading can occur separately and occasionally.

Received power fading is caused by variations in the atmosphere which produce a change in beam bending that in turn changes the path clearance relative to obstacles along the path. These obstacles

could be the earth itself, trees, buildings, etc. Received power fading can also be caused by signals being trapped in an atmospheric duct. Such trapping can result in variations in the received signal strength because of obstacle blockage or off-axis arrival of the beam on the receive antenna.

The probability and depth of fade from these causes can be reduced by providing proper path clearance between the transmit and receive antennas. Insuring appropriate terrain clearance and antenna height has the effect of keeping the microwave beam above the intervening terrain under varying atmospheric conditions. The path clearance criteria are satisfied by the following means.

Antenna tower heights on each radio link shall be determined such that the antennas are unobstructed and have a clearance above path terrain and obstacles on the link. The antenna beam path shall meet or exceed the following conditions:

a. For space diversity systems, all top-to-bottom antenna beam paths shall have a 0.3 Fresnel zone clearance (see references [9], [10], and [11] for K = 2/3, where K is the effective earth's radius factor.

b. For non-diversity radio links, the beam path between the single antennas at each end of the link shall have a 0.3 Fresnel zone clearance for K = 2/3.

c. If year round refractive index statistics are available for the particular geographic area of concern, all top-to-top antenna

beam paths must meet or exceed grazing conditions for 99.99% of the year.

4. FADE MARGIN CRITERIA

Once a path has adequate clearance, the short term fading caused by multipath phenomenon is relatively independent of path clearance, and in its extreme condition, approaches the Rayleigh distribution.

Multipath fading is caused by reflections from ground or water surfaces and refractions or reflections by inhomogeneities in the atmosphere. In any of these types of fading, microwave energy propagated via indirect paths adds to the energy transmitted over the direct path to produce a vector sum. Depending upon the difference in path lengths between the indirect paths and the direct path, the indirect wave may arrive at the receiving antenna either in phase, out-of-phase, or partially out-of-phase with the direct wave.

To protect a radio link from frequent channel disturbances or outages caused by multipath fading, an adequate fade margin must be designed into the system. As defined in reference [1], fade margin is the difference, in dB, between the normal unfaded received signal level (RSL) and the threshold RSL corresponding to a bit error probability of 10^{-4}. A fade outage occurs when the received signal level falls below the threshold RSL defined above. The probability of fade outage per call minute occuring for a fade outage duration (FOD) between the limits of t_1 and t_2 is given in reference [1], equation (7) as:

$$\Pr(t_1 < FOD < t_2) = \frac{60}{MTBFO\ (t_1,\ t_2)} \tag{1}$$

where MTBFO is the mean-time-between-fade-outages for the duration of t_1 and t_2 and they are respectively the lower and upper fade outage duration limits, in seconds. By substituting equations (3), (4), (5), and (6) of reference [1] into the above equation the relationship between fade margin on a link and the fade outage probability per call minute is derived as follows:

$$\Pr(t_1 < FOD < t_2) = \frac{60\,P_o\left[e^{-1.15\left[\frac{t_1}{t_o}\right]^{2/3}} - e^{-1.15\left[\frac{t_2}{t_o}\right]^{2/3}}\right]}{t_o} \tag{2}$$

where, t_o = the mean duration of fade below threshold, in seconds.

t_1 = the lower limit of fade duration, in seconds.

t_2 = the upper limit of fade duration, in seconds.

P_o = the probability that the RSL is below threshold.

The equality is assumed since for all reasonable link designs MTBFO (t_1, t_2) will be much larger than 60.

If we let:

$$Z(M_F,\ D,\ f) = \frac{60\left[e^{-1.15\left[\frac{t_1}{t_o}\right]^{2/3}} - e^{-1.15\left[\frac{t_2}{t_o}\right]^{2/3}}\right]}{t_o} \tag{3}$$

and substitute equation (3) into (2) we arrive at:

$$Pr(t_1 < FOD < t_2) = P_o \; Z(F,D,f). \tag{4}$$

Upon substituting equation (1) of reference [1] into equation (4) above and solving for fade margin, F, we now obtain the relationship between fade margin and fade outage probability, which is written as:

$$M_F = -5 \log_{10} \left[\frac{56 \; S^2 \; P_o \; Z(M_F,D,f)}{(r^2 + \frac{1}{r^2}) \; acD^4} \right]. \tag{5}$$

After converting the units in the above equation from English to the metric system, substituting k for $(r^2 + \frac{1}{r^2})$, and having t_1 equal 5 seconds and t_2 equal 60 seconds, we arrive at the following equation:

$$M_F \; (dB) = -5 \log_{10} \left[\frac{4047 \; S^2 \; Pr \; (5 < FOD < 60)}{k \; a \; c \; D^4} \right] \tag{6}$$

where: M_F = fade margin in dB

Pr (5 < FOD < 60) = the design criterion and the probability that the fade outage duration is greater than 5 seconds but less than or equal to 60 seconds (fade outage Type III, reference [1] .

For space diversity:

S = antenna separation in meters, ($S \leq 15.2$ m).

For frequency diversity:

$$S = \left[\frac{DY\,\Delta f}{f^2}\right]^{1/2}$$

D = path length in km

Δf = frequency separation in MHz

f = frequency in GHz

Y = 17.4 for 2 GHz

4.4 for 4 GHz

1.1 for 8 GHz

$$r^2 = 10^{\frac{R}{10}}$$

R = diversity combiner hysteresis ratio in dB

a = 0.005 ^{o}F, ($35^{o} \leq F \leq 75^{o}$), is percentage of the year that constitutes the fading season

^{o}F = average annual temperature of the locality in question in degrees fahrenheit

$$c = b\left[\frac{w}{15.0}\right]^{-1.3}$$

c = climate and terrain factor

$$b = \begin{cases} 2 & \text{coastal areas} \\ 1 & \text{average climate} \\ 0.5 & \text{dry climate} \end{cases}$$

$$w = \left[\frac{1}{N} \sum_{i=1}^{N} (x_i - \overline{x})^2\right]^{\frac{1}{2}} \quad \text{in meters. (Terrain roughness factor)}$$

The terrain roughness factor (standard deviation, of path elevations above mean sea level (MSL)), is the square root of the average square of the deviation from the mean, where x_i is the terrain height at each kilometer, excluding the end points, and $\overline{x}$ is the mean of the terrain heights above mean sea level. Applicable values of w range from 6 meters (smooth) to 42 meters (rough); values of 6 and 42 should be used when calculated values of w are less than 6 or larger than 42 respectively.

$Z(M_F, D, f)$ is a factor which depends upon fade margin and distance and frequency. For our ranges of distances and fade margins, this is approximately equal to 3.5. For the final determination of whether a particular link meets the specified design criterion, this function is contained in Figure B-3 in Appendix B of this paper.

As can be seen from equation (6), fade margin is dependent upon the fourth power of path length; therefore the fade margin design criterion was derived as a function of path length.

In an effort to develop practical limits for cost-effective design of LOS links the following constraints were considered and trade-offs made in deriving the fade margin criteria:

a. With the system gain specified for the DRAMA radio, an LOS link of 161 km (100 miles) should not under normal conditions require an antenna size greater than 4.57 m (15 feet), and a nominal 48.3 km

(30 mile) link design should be achievable with a 2.44 m (8 feet) antenna.

b. To satisfy the allocated fade outage probabilities for the 965 km (600 mile) reference circuit specified in Table II of reference [1] in a cost effective manner, the fade margin requirements for longer links (expensive to achieve) are relaxed, and the fade margin requirements for shorter links (easier to achieve) are tightened. The break point and allocation of requirements between short and long links will be such that, for a realistic representative distribution of DCS links comprising the above reference circuit, the allocated fade outage probabilities will be met.

The distribution of LOS path lengths in the DCS very closely follows a log normal distribution with a median of 32 km (20 miles) and a standard deviation of 30 km (18.6 miles), as shown in Figure 2. This median value produces a convenient breakpoint between long and short LOS paths of 32 km (20 miles).

Applying the considerations stated above, the fade margin objective is divided into two parts, one for DCS LOS paths up to 32 km, and one for LOS path lengths equal to or greater than 32 km.

(1) <u>For D less than 32 km</u>:

$$M_F = 20 \log D + 2 \text{ (dB)}$$

(2) <u>For D equal to or greater than 32 km</u>:

$$M_F = 9 \log D + 18 \text{ (dB)}$$

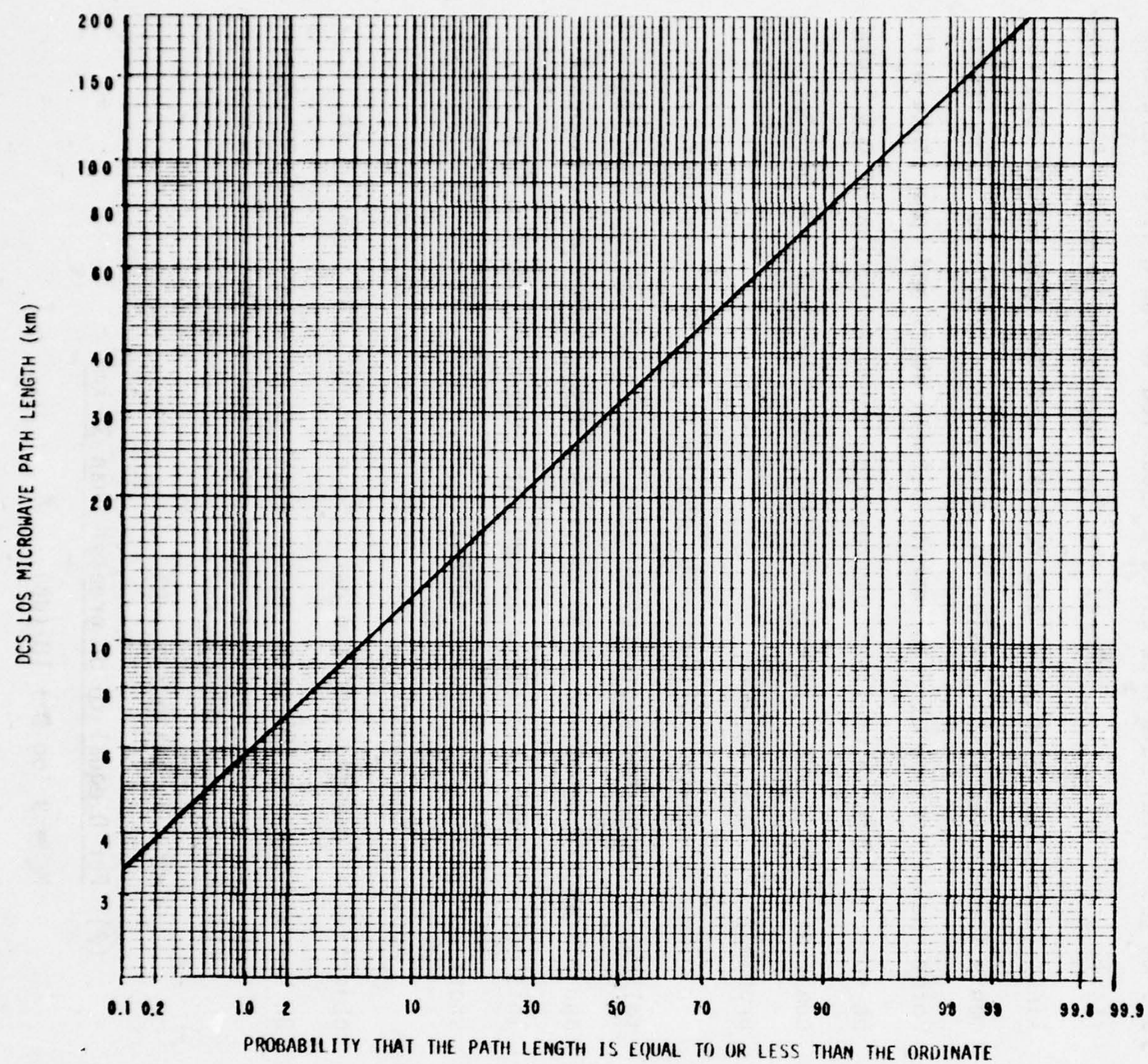


Figure 2. LOS Path Length Distribution in the DCS

where: M_F = fade margin in dB

D = path length in km.

Figure 3 illustrates the relationships between fade margin and path length, and the probability of a fade outage greater than 5 seconds under average climate and terrain conditions. The heavy line is a plot of the fade margin criterion developed above, which when applied to the 965 km (600 mile) reference circuit satisfies the fade outage probability requirement for outage Type III in Table I. The above derived fade margin criterion was applied to actual DEB I and DEB III DCS segments of approximately 965 km (600 mile) path length. In both examples the Fade Outage Criterion for outage Type III was met or exceeded.

When determining the total link margin required for any RF link, a miscellaneous loss margin of 6 dB is added to the fade margin derived in the above paragraph. The 6 dB margin is required to account for minor antenna misalignment and system gain degradation (e.g., waveguide corrosion, receiver noise due to aging), atmospheric absorption, rain and polarization losses, etc. Thus the total link margin (M_L) design objective is:

$M_L = 20 \log D + 8$ (dB); for D less than 32 km (20 miles)

$M_L = 9 \log D + 24$ (dB); for D equal to or greater than 32 km (20 miles).

This link margin is used in the transmission equation to determine the necessary system parameters, such as antenna diameters, and antenna spacing for diversity operation.

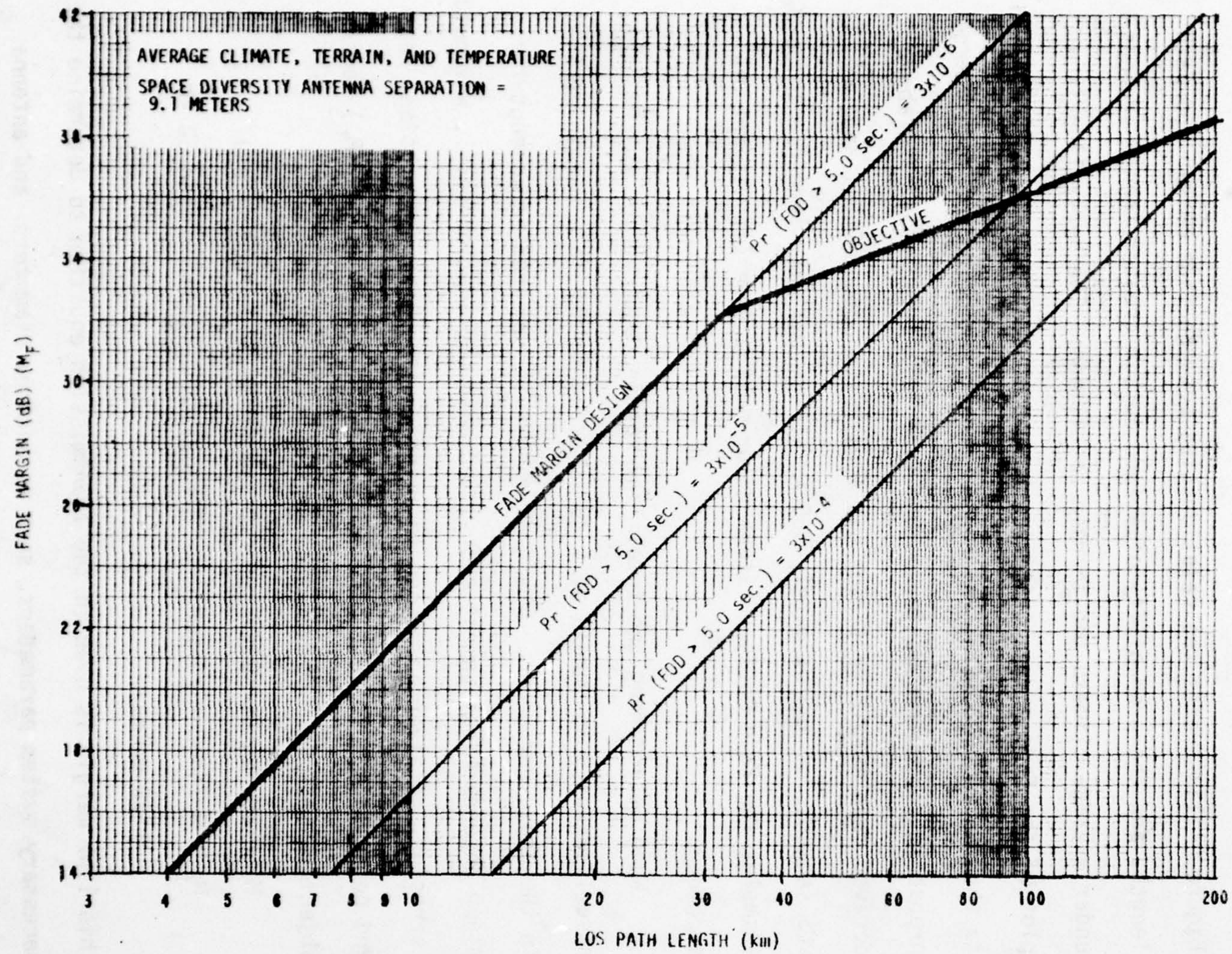


Figure 3. Fade Margin Design Objective versus Path Length for LOS Microwave Links. (Also, Probability of a Fade Outage Duration Greater than 5 Seconds versus Fade Margin and Path Length for the Case of Average Climate, Terrain, and Temperature and Dual Space Diversity with Vertical Antenna Separation of 9.1 Meters.)

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GLOSSARY OF TERMS AND ACRONYMS

SYSTEM AVAILABILITY: The ratio of total system "up" time to total observation time. Takes into account all sources of outage (unavailability) such as, but not limited to, equipment, propagation media, restoral, and maintenance outage.

BER: Bit Error Rate.

BIT ERROR RATE: The ratio of the number of bits transmitted in error, for a specific time, to the total number of bits transmitted during the same period.

DIGITAL PERFORMANCE THRESHOLD: That value of RSL corresponding to a bit error probability of 10^{-4} under non-fading conditions.

FADE MARGIN: The difference, in dB, between the median, unfaded received signal level (RSL) and the digital performance threshold received signal level (10^{-4} bit error probability).

FOD: Fade Outage Duration.

FOR: Fade Outage Rate.

LINK MARGIN: Link Margin is the sum, in dB, of the fade margin and a loss margin of 6dB. This loss margin is required in addition to the fade margin to take into account initial link implementation losses, minor antenna misalignment, system gain degradation, (e.g., waveguide corrosion, receiver noise due to aging), atmospheric absorption, rain and polarization losses that may occur.

LOS: Line of Sight.

RADIO LINK: A radio link consists of that portion of the RF system from one modulator through the radio and propagation media, through the receiver and demodulator. It is also referred to as an RF hop.

RECEIVER SENSITIVITY: As defined is the same as DIGITAL PERFORMANCE THRESHOLD.

RSL: Received Signal Level.

SYSTEM GAIN: System gain is the difference between the power output of the transmitter, as delivered to the transmit waveguide, and the DIGITAL PERFORMANCE THRESHOLD of the receiver as measured at its interface with the receiver waveguide.

GLOSSARY OF TERMS AND ACRONYMS

(Continued)

PROPAGATION FADING: Temporary and random fluctuations of the received signal, dependent on certain meterological conditions, both seasonal and local. Fading intensity generally increases with the carrier frequency and with the length of the path.

E_b/N_o: is the ratio of energy per information bit to receiver noise in a one Hertz bandwidth.

MTBFO: Mean Time Between Fade Outage.

APPENDIX A

DIGITAL LOS PATH CALCULATION PROCEDURE

This appendix provides a detailed procedure for calculating parameters for digital DCS LOS transmission links that will meet the system performance and availability criteria established in DCEC TR 12-76, dated November 1976 [1]. With the assumption that the path under consideration is feasible from a path clearance standpoint, digital LOS path calculations can be performed by utilizing the step-by-step procedure in Table A-I, provided at the end of this appendix. The following paragraphs explain each item in the procedure.

Item 1. From system frequency plan, or use the mid-band frequency if specific frequencies have not been selected. If frequency diversity is employed, use the higher frequency, in GHz.

Item 2. Enter the path length, in km, determined from the map study or from site records for existing paths.

Items 3, 9, and 13. Enter the antenna heights above local ground, in meters, determined from the path profile or existing site information.

Items 4 and 10. Enter the horizontal waveguide run length, in meters, from site records. If unknown, use 15 meters for planning purposes.

Items 5 and 11. Obtain total transmission line lengths, in meters. This is the sum of the vertical antenna run and the horizontal run.

Item 6. Enter the selected transmission line type for use on the system.

Item 7. Obtain transmission line loss factor for the transmission line in use, in dB/meter, from Table A-II or manufacturer's data.

Items 8 and 12. Multiply transmission line loss factor times each of Items 5 and 11 to obtain total waveguide losses, in dB, for each case.

Items 14 and 15. Self-explanatory.

Item 16. The median LOS free space loss is the sum of Items 14 and 15 plus 92.5.

Item 17. Total system loss for the transmitter and upper receiving antenna transmission line including free space loss, is the sum of Items 16, 8 and 12.

Item 18. The transmitter output power, in dBm, is obtained from the system design documents, or equipment manuals, and is the power delivered to the waveguide port immediately on the outboard side (closest to antenna) of the waveguide switches and circulators.

Item 19. Thermal noise is the factor which sets the lower limit on the sensitivity of a receiving system. Thermal noise is directly proportional to bandwidth (bit rate) and temperature. The amount of

thermal noise in 1 Hz of bandwidth in an actual device is given by:

$$P_n = kT_o = -174 \text{ dBm/Hz}$$

where: k = Boltzmann's constant (1.3803×10^{-23} J/^oK)

T_o = absolute temperature (^oK) = 290^oK (room temperature).

<u>Item 20</u>. Receiver noise figure N_f, in dB, is obtained from the system design documents, or equipment specifications.

<u>Item 21</u>. The receiver noise power spectral density, N_o, in dBm/Hz, is obtained by summing Items 19 and 20, N_o is also referred to as the noise power in 1 Hz bandwidth, and the one-sided noise spectral density:

$$N_o = kT_oN_f.$$

If the receiver noise figure is not known, and the RSL threshold (faded) is known, go to Item 25.

<u>Item 22</u>. Modulation bit rate is obtained from the system documents and is expressed in bits/second and is the rate at which digital information, in bits, is transmitted through the RF system.

<u>Item 23</u>. Self-explanatory.

<u>Item 24</u>. E_b/N_o is obtained from equipment specifications and is the signal power efficiency for the modulation technique used. E_b/N_o is the required energy per data bit per noise power spectral density to achieve a particular probability of bit error at the 10^{-4} threshold, unless otherwise specified. This item is given in Table A-III

for the equipments planned for the DCS. For other equipments, the E_b/N_o value should be taken from their equipment specifications.

Item 25. The faded RSL is the level below which the probability of bit error is greater than 10^{-4}. This level can be obtained by summing the thermal noise per Hertz, energy per bit divided by noise power density, and the receiver noise figure, all in units of dB or dBm, or from equipment specifications.

Item 26. The fade margin required to meet the design objectives established in DCEC TR 12-76 [1].

The required minimum fade margin, as a function of path length, is:

if Item 2 is less than 32 km,

$$M_F = 20 \log (\text{Item } 2) + 2 \text{ dB}$$

if Item 2 is equal to or greater than 32 km,

$$M_F = 9 \log (\text{Item } 2) + 18 \text{ dB.}$$

Item 27. The above fade margin was obtained assuming the path was in a geographical area of average terrain, average climate and average temperature. If the particular path does not fit these assumptions, Table A-IV should be consulted to determine a fade margin correction factor. This number is entered as Item 27. Yearly average temperature is assumed to be 50^{o}F.

Item 28. The terrain/climate/temperature corrected fade margin, M_{fc}, is the sum of Items 26 and 27.

Item 29. A miscellaneous loss margin of 6 dB is added to account for link implementation losses such as minor antenna misalignment, system gain degradation, waveguide corrosion, and receiver noise figure increases (due to aging) which occur over the lifetime of the system.

Item 30. Total link margin is the sum of Items 28 and 29. The link margin design objective is then:

$$M_L = M_{fc} + 6 \text{ dB}.$$

Item 31. The total antenna gain (both ends) required to provide the necessary link margin is the sum of Items 25, 30, and 17 minus 18:

$$2G_A = RSL_f + M_L + L_{sys} - P_T.$$

Item 32. The appropriate antenna diameter is determined from Table A-IV. Choose the antenna diameter which has a gain value within +1 or -2 of one half of Item 31. If the antenna diameter determined above is greater than 4.57 m (15 feet), one or more of the following things can be done to obtain more system gain:

(1) Increase transmitter power

(2) Use lower loss transmission line

(3) Use lower noise receiver

(4) Separate space diversity antennas (max. 15 meters)

(5) Use higher order of diversity.

This completes the design methodology for determining the required system parameters to satisfy the performance requirements of reference [1]. Appendix B presents a methodology for determining

whether the design meets or exceeds the fade outage probability requirements, once the system parameters are determined or given.

TABLE A-II

TRANSMISSION LINE LOSS FACTOR (dB/meter)

TRANSMISSION LINE TYPE	FREQUENCY BAND (GHz)			
	2	4	6	8
Waveguide (rectangular)	-	0.041	0.065	0.085
Waveguide (elliptical)	-	0.045	0.057	0.065
Waveguide (circular)	-	0.014	0.030	0.022
Coaxial	0.045	0.070	-	-

TABLE A-III

MICROWAVE RADIO PERFORMANCE PARAMETERS

LOS RADIO TYPE	Required E_b/N_o for BER = 10^{-4} (See Note)
1. AN/FRC-162 (3LPR Modulation)	16 dB
2. DRAMA Radio AN/FRC-( ) ( ) (1 bit/s/Hz, nominal)	14 dB
3. DRAMA Radio AN/FRC-( ) ( ) (2 bit/s/Hz, nominal)	20 dB

NOTE: Receiver noise assumed to be 10 dB, and system gain to be as specified in TR 12-76 [1].

TABLE A-IV

FADE MARGIN CORRECTION FACTOR (dB)

Annual Average Temperature	Terrain	Climate (Humidity)		
		Dry	Average	Coastal
Hot Temperature	Smooth	+1.8	+3.3	+4.9
	Average	-0.8	+0.7	+2.2
	Rough	-3.7	-2.2	-0.7
Average Temperature	Smooth	+1.1	+2.6	+4.1
	Average	-1.5	0	+1.5
	Rough	-4.4	-2.2	-1.4
Cool Temperature	Smooth	0.0	+1.5	+3.0
	Average	-2.6	-1.1	+0.4
	Rough	-5.5	-4.0	-2.6

TABLE A-V

PARABOLIC ANTENNA GAIN

PARABOLIC ANTENNA DIAMETER		FREQUENCY BAND					
		2 GHz		4 GHz		8 GHz	
		G_A	$2G_A$	G_A	$2\ G_A$	G_A	$2G_A$
(ft)	(Meters)	(dBi)	(dBi)	(dBi)	(dBi)	(dBi)	(dBi)
4	1.22	25.3	50.6	31.3	62.6	37.3	74.6
6	1.83	28.8	57.6	34.8	69.6	40.8	81.6
8	2.44	31.3	62.6	37.3	74.6	43.3	86.6
10	3.05	33.3	66.6	39.3	78.6	45.3	90.6
12	3.66	34.8	69.6	40.8	81.6	46.8	93.6
15	4.57	36.8	73.6	42.8	85.6	48.8	97.6

TABLE A-I
DIGITAL LOS PATH CALCULATION PROCEDURE

LOS Path: __________ to __________

1.	Frequency, f	________GHz	From system plan
2.	Path Length, d	________km	From map study or site records
3.	Transmitter Antenna Height above ground	________m	From site records or path profile
4.	Transmitter Horizontal Transmission Line Length	________m	From site records
5.	Total Tx Transmission Line Length	_______m	Item 3 + Item 4
6.	Transmission Line Type: rectangular ( ), elliptical ( ), circular ( ), coaxial ( ),	_______	Transmission line selected for use on the system.
7.	Transmission Line Loss Factor	_______dB/m	For particular waveguide in use (See Table A-II) or manufacturer data).
8.	Total Tx Transmission Line Loss	_______dB	Item 7 x Item 5
9.	Receiving Antenna Height above ground (Upper antenna if space diversity is used)	_______m	From site records or path profile
10.	Receiving Horizontal Transmission Line Length	_______m	From site records
11.	Total Receiving Transmission Line Length	_______m	Item 9 + Item 10
12.	Total Rx Transmission Line Loss	_______dB	Item 7 x Item 11

TABLE A-I
(Continued)

13.	Lower Receiving Antenna Height above ground (If space diversity is used)	______ m	From site records or path profile. The antenna spacing is ______ meters. (Item 48 in Appendix B).
14.	20 $\log_{10}$ (Item 1)	______ dB	
15.	20 $\log_{10}$ (Item 2)	______ dB	
16.	LOS Free Space Loss (median), L_{fs}	______ dB	Item 15 + Item 14 + 92.5
17.	Total Losses (Tx and Upper Rx Antenna), L_{sys1}	______ dB	Item 16 + Item 8 + Item 12
18.	Transmitter Power, P_T	______ dBm	From system design documents, and text
19.	Thermal Noise per Hertz, KT_o	-174 dBm/Hz	$P_n = KT_o$
20.	Receiver Noise Figure, N_f	______ dB	From system documents or equipment specifications
21.	Receiver Noise Density, N_o	______ dBm/Hz	Item 19 + Item 20
22.	Modulation Bit Rate, B_r	______ bits/sec	From system documentation
23.	10 $\log_{10}$ (Item 22)	______ dB	
24.	Required E_b/N_o for BER = 10^{-4}	______ dB	

APPENDIX B

DETERMINATION OF FADE OUTAGE PROBABILITY PER CALL MINUTE ON A LOS LINK

The purpose of this appendix is twofold:

1. To check the design parameters which were determined in Appenaix A.
2. To determine whether an existing link meets the fade outage probability criteria developed in reference [1].

The step-by-step procedure for this calculation is given in Table B-I, provided at the end of this appendix. The following paragraphs explain each item in the procedure. Items previous to Item 33 are found and described in Appendix A.

Item 33. The single antenna gain (at one end) is obtained from Table A-V, the following formula, or manufacturer's data:

$$G_A = 21 \log f\ (\mathrm{GHz}) + 20 \log D_{(m)} + 17.52.$$

Item 34. The unfaded RSL is obtained by summing Items 18 and two times Item 33, minus Item 17.

$$RSL_{unfaded} = P_T + 2G_A - L_{sys}.$$

Item 35. The actual fade margin is obtained by subtracting from Item 34, Item 25 and 6 dB, and is the fade margin of the system at a bit error probability of 10^{-4} which is used to determine the probability of a fade outage lasting between 5 and 60 seconds.

Item 36. Average annual temperature, in ^{o}F, from area weather bureau. If this information is unavailable, use 70^{o}F for hot, 50^{o} for average and 30^{o} for cool regions.

Item 37. Portion of year which constitutes the fading season is obtained by multiplying Item 36 by 0.005.

Item 38. Terrain roughness is the standard deviation of terrain heights above sea level, obtained from the path profile at one-mile intervals, with the ends of the path excluded, and is denoted by W. Applicable values of W range from 6 meters ("smooth") to 42 meters ("rough"). Values of 6 and 42 should be used, when calculated values of W are less than 6 or larger than 42, respectively. Terrain roughness factor, W, is entered in meters.

Item 39. Item 38 is divided by 15, which is the average value of W.

Item 40. Item 39 is raised to the minus 1.3 power.

Item 41. The climate factor, k, is chosen and entered here.

$$k \begin{cases} = 2 \text{ for humid or coastal areas} \\ = 1 \text{ for average climate} \\ = 0.5 \text{ for dry or desert climate.} \end{cases}$$

Item 42. The combined climate and terrain factor, c, is obtained by multiplying Item 41 times Item 40. This factor can also be obtained from Figure B-III.

Item 43. The probability that the RSL is below threshold is also a function of the hysteresis effect in the diversity switching process. The diversity switch hysteresis ratio is obtained by:

$$r^2 = \log^{-1}_{10} \left[\frac{R}{10} \right]$$

where R is the hysteresis in dB.

For those cases where the hysteresis is unknown, use R = 4 dB; therefore Item 43 is 2.51.

Item 44. Item 43 plus the reciprocal of Item 43.

Item 45. Item 2 to the fourth power times 0.149.

Item 46. Item 35 divided by 5.

Item 47. Ten to the minus (Item 46) power.

Item 48. Space diversity antenna vertical spacing in meters, but not greater than 15 meters. For frequency diversity systems use the following for Item 48.

$$(\text{Item 48}) = \left[\frac{H\ D\ \Delta f}{f^2} \right]^{1/2}$$

where

$$H = \begin{cases} 17.4 & \\ 4.35 & \text{for} \\ 1.1 & \end{cases} \begin{matrix} 2\ \text{GHz} \\ 4\ \text{GHz} \\ 8\ \text{GHz} \end{matrix}$$

D = path length in kilometers (Item 2)

Δf = frequency separation in MHz

f = frequency in GHz (Item 1).

Item 49. The diversity factor is obtained by multiplying 10.765 times Item 48 squared.

Item 50. 56 times Item 49.

Item 51. Product of Items 44, 37, 42, 45, and 47.

Item 52. Probability that the calculated unfaded RSL is below threshold, and is obtained by taking the quotient of Item 51 and Item 50.

Item 53. A $Z(M_F, D, f)$ factor is obtained by using the equation below, or Figure B-3, for particular values of Items 35, 2, and 1.

$$Z(M_F, D, f) = \frac{60\left[e^{-1.15\left[\frac{5}{t_o}\right]^{2/3}} - e^{-1.15\left[\frac{60}{t_o}\right]^{2/3}}\right]}{t_o}$$

where: $t_o = 0.141\ g\ (D)^{\frac{1}{2}}\ 10^{-M_F/20}$

$$g = \begin{cases} 560 \text{ for } 2 \text{ GHz} \\ 400 \text{ for } 4 \text{ GHz} \\ 280 \text{ for } 8 \text{ GHz} \end{cases} \quad \text{see Item } 1$$

M_F = fade margin in dB (Item 35)

D = path length in km (Item 2).

Item 54. The probability of a fade outage per call minute, lasting between 5 seconds and 1 minute, is obtained by multiplying the $Z(M_F, D, f)$ factor, Item 53 times Item 52.

$$P_r\ (5\ s < FOD < 60\ s) = Z(M_F, D, f).$$

Item 55. Item 2 times 2.6 times 10^{-7}.

Item 56. The quotient of Item 54 and Item 55.

If Item 56 is greater than 2.0, the recommended course of action is to increase system gain by performing one or more of the following actions until Item 56 is equal to or less than 2.0:

(1) Increase antenna size

(2) Increase transmitter power

(3) Use lower loss transmission line

(4) Use lower noise receiver

(5) Separate space diversity antennas (max. 15 meters)

If Item 56 cannot be made lower than 2.0 by implementing the above techniques, the design should be considered a special case, which should be handled by means other than the procedures presented herein. Some alternative would be to seek another LOS path or employing repeaters.

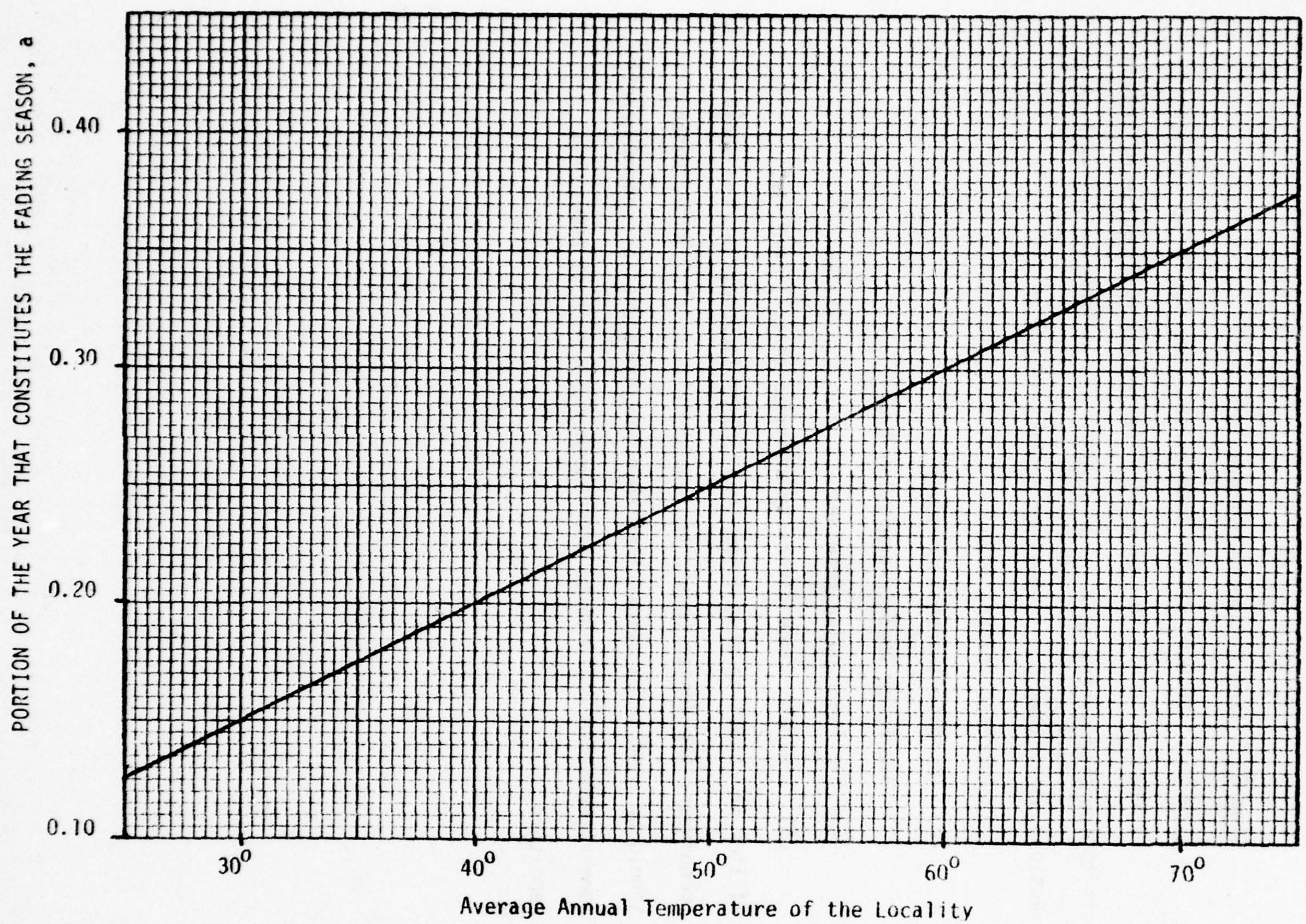

Figure B-1. Length of the Fading Season as a Function of Temperature

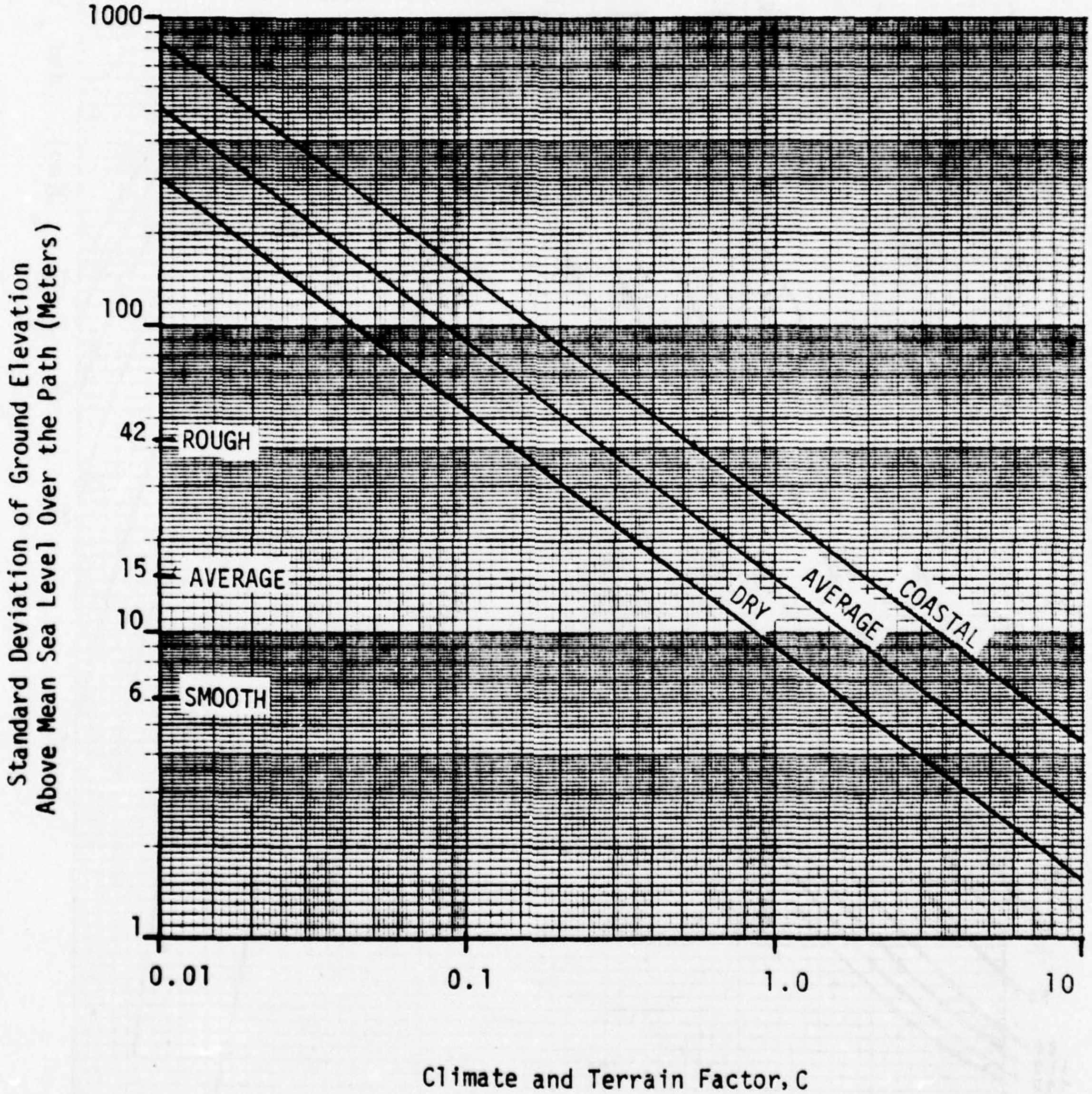

Figure B-2. C Factor as a Function of Terrain **Roughness** and Climate

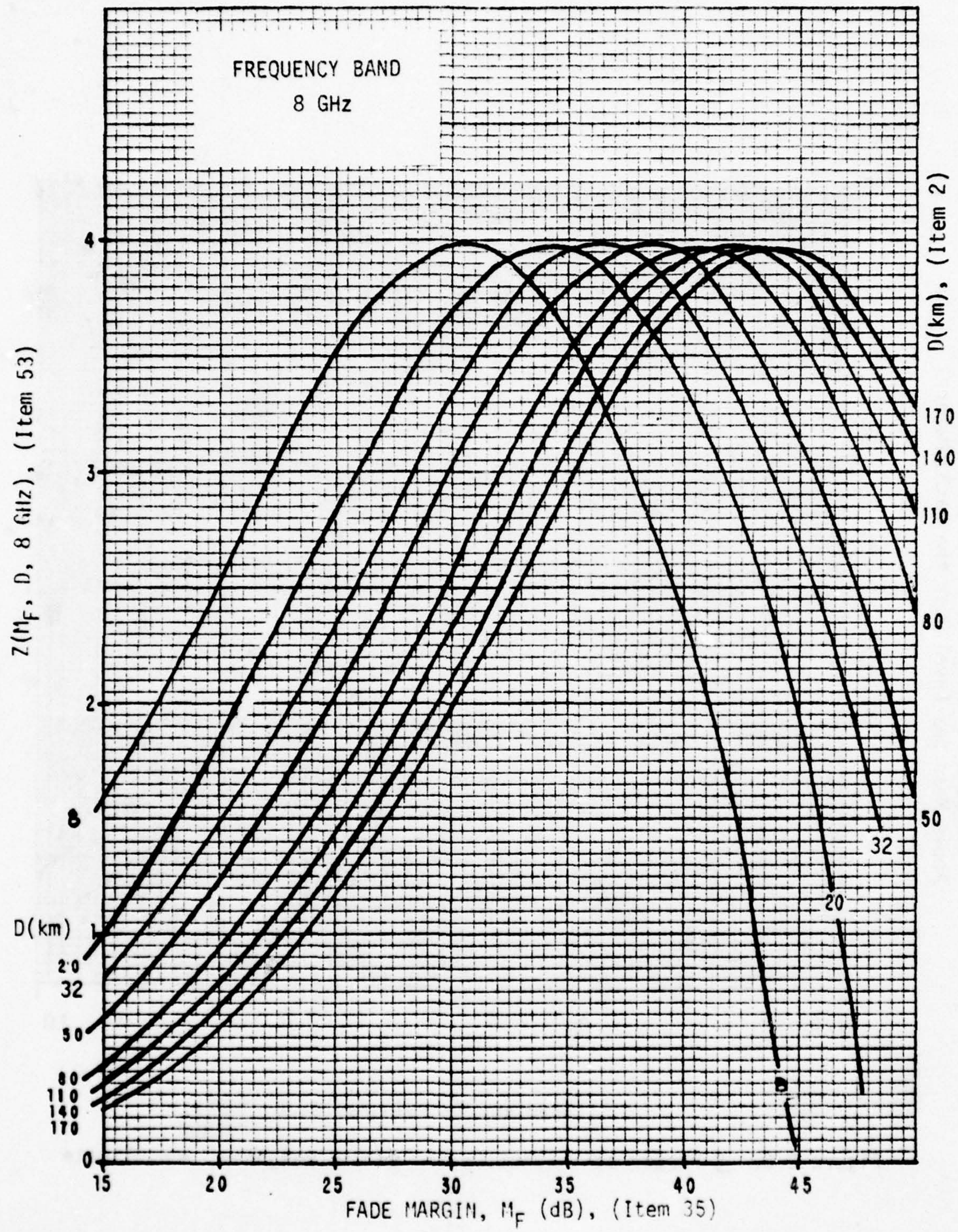

Figure B-3a. Z Factor as a Function of Fade Margin and Path Length, for the 8 GHz Frequency Band

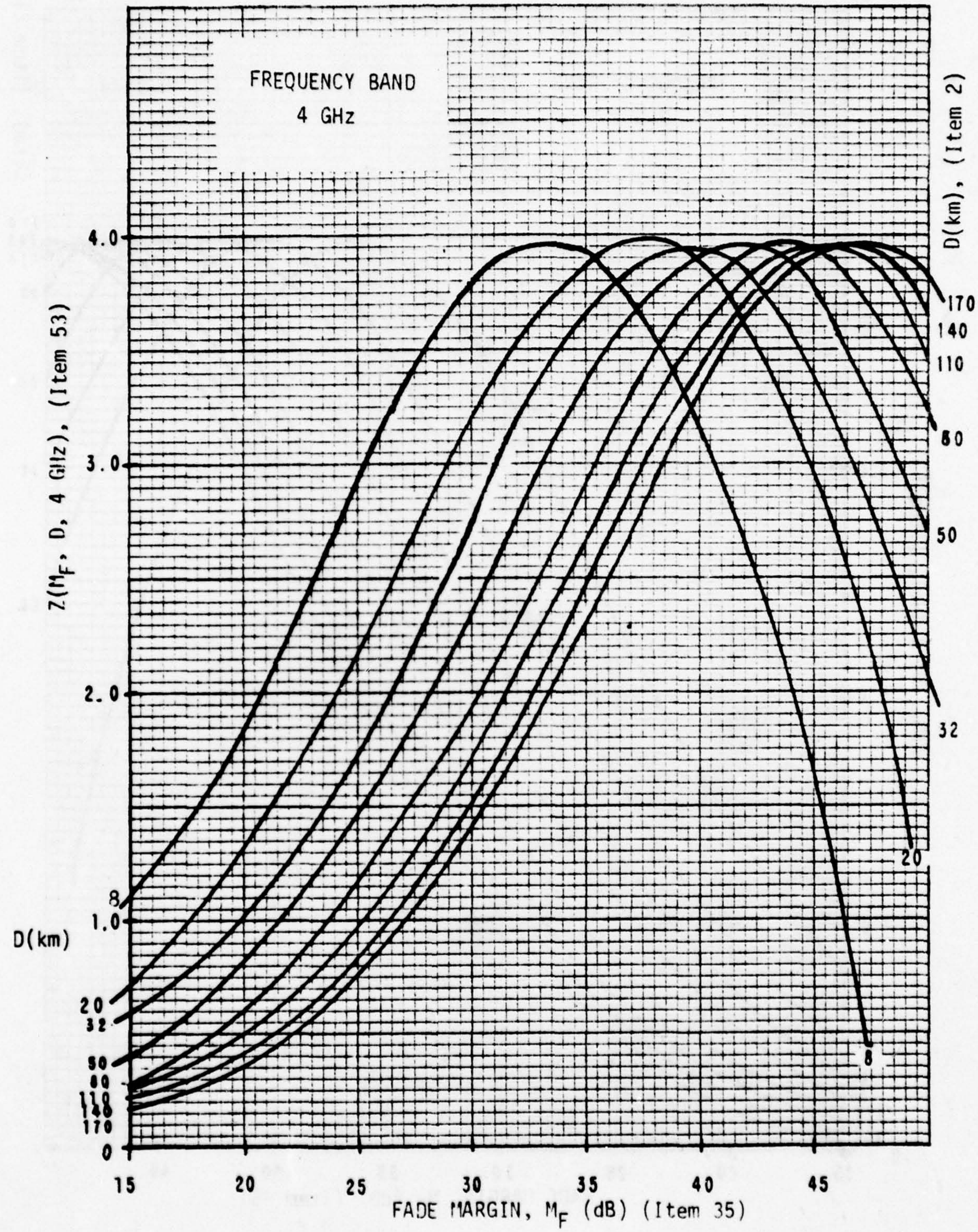

Figure B-3b. Z Factor as a Function of Fade Margin and Path Length, for the 4 GHz Frequency Band

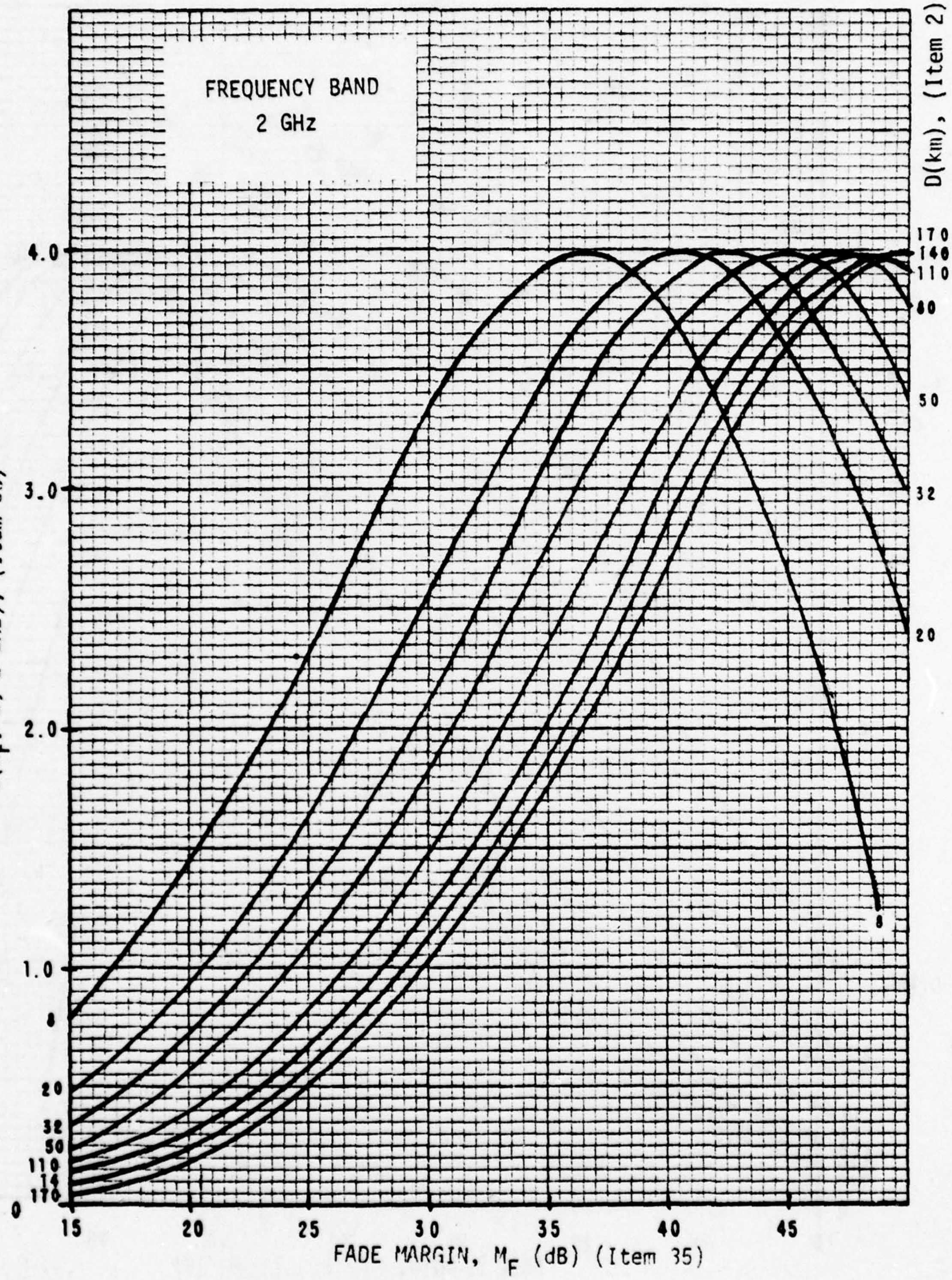

Figure B-3c. Z Factor as a Function of Fade Margin and Path Length, for the 2 GHz Frequency Band

TABLE B-I

DETERMINATION OF FADE OUTAGE PROBABILITY PER CALL MINUTE

(5 sec < FOD* < 60 sec)

(NOTE: Items previous to 33 are found in Appendix A.)

33.	Single Antenna Gain	______dBi	Item 14 + 20 log (Item 32) + 17.52, or from Table A-V, or from manufacturer's data.
34.	Unfaded RSL, RSL_{uf}	______dBm	Item 18 + 2 x (Item 33) - Item 17
35.	Actual Fade Margin, M_{fa}	______dB	Item 34 - Item 25 - 6
36.	Average Yearly Temperature, T_{ave}	______^{o}F	Area Weather Bureau (See text)
37.	Portion of the Year that Constitutes the Fading Season, a	______	0.005 x (Item 36), or from Figure B-I
38.	Terrain Roughness Factor, W	______m	From path profile, and see text.
39.	Item 38 ÷ 15	______	
40.	$(\text{Item } 39)^{-1.3}$	______	
41.	Climate Factor, K	______	

For item 38:

W = 6 m, smooth earth; 15 m, average earth; 42 m, rough earth

For item 41:

K = 2, humid (coastal); 1, average; 0.5, dry

*Note: FOD = Fade Outage Duration

42.	Climate and Terrain Factor, C	______	Item 41 x Item 40, or from Figure B-II text
43.	Diversity Switch	______	$r^2 = \log^{-1}\left[\frac{R}{10}\right]$ where R = hysteresis in dB; if R is unknown use $r^2 = 2.51$.
44.	Item 43 + (1 ÷ Item 43)	______	See text.
45.	0.149 x $(\text{Item } 2)^4$	______	
46.	Item 35 ÷ 5	______	
47.	$10^{-(\text{Item } 46)}$	______	
48.	Receive Antenna separation for space diversity system	______ m	From system documents or see text
	or equivalent factor for frequency diversity system	______	See text for explanation.
49.	Diversity Factor	______	10.765 x $(\text{Item } 48)^2$
50.	56 x Item 49	______	
51.	Item 44 x Item 37 x Item 42 x Item 45 x Item 47	______	
52.	Probability RSL is below threshold P_o	______	Item 51 ÷ Item 50
53.	$Z(M_F, D, f)$ factor	______	See text.
54.	Probability of a fade outage with a duration in the range of between 5 seconds and 60 seconds	______	Item 53 x Item 52

0

to determine whether the above design meets the design criteria continue as follows.

55. Item 2 x (2.6×10^{-7}) ______

56. Item 54 ÷ Item 55 ______ (Should be less than 2.0)

57. If Item 56 is greater than 2.0 the recommended course of action is increase the system gain by performing one or more of the following, until a ratio of 2.0 or less in Item 56 above is obtained:

a. Increase antenna size

b. Increase transmitter power

c. Use lower loss transmission line

d. Use lower noise receiver

e. Separate space diversity antennas (max. 15 meters)

f. Use higher order of diversity.

EXAMPLE C-1

TABLE A-I

DIGITAL LOS PATH CALCULATION PROCEDURE

LOS Path: - ABC to XYZ

1.	Frequency, f	8 GHz	From system plan
2.	Path Length, d	18.7 km	From map study or site records
3.	Transmitter Antenna Height above ground	21.3 m	From site records or path profile
4.	Transmitter Horizontal Transmission Line Length	15.0 m	From site records
5.	Total Tx Transmission Line Length	36.3 m	Item 3 + Item 4
6.	Transmission Line Type: rectangular ( ), elliptical (EW-71), circular ( ), coaxial ( ),	ellip.	Transmission line selected for use on the system.
7.	Transmission Line Loss Factor	0.065 dB/m	For particular waveguide in use (See Table A-II) or manufacturer data).
8.	Total Tx Transmission Line Loss	2.36 dB	Item 7 x Item 5
9.	Receiving Antenna Height above ground (Upper antenna if space diversity is used)	53.3 m	From site records or path profile
10.	Receiving Horizontal Transmission Line Length	15.0 m	From site records
11.	Total Receiving Transmission Line Length	68.3 m	Item 9 + Item 10
12.	Total Rx Transmission Line Loss	4.44 dB	Item 7 x Item 11

EXAMPLE C-1
(TABLE A-I, Continued)

13.	Lower Receiving Antenna Height above ground (If space diversity is used)	15.0	m	From site records or path profile. The antenna spacing is 9.14 meters. (Item 48 in Appendix B).
14.	20 $\log_{10}$ (Item 1)	18.06	dB	
15.	20 $\log_{10}$ (Item 2)	25.44	dB	
16.	LOS Free Space Loss (median), L_{fs}	136.0	dB	Item 15 + Item 14 + 92.5
17.	Total Losses (Tx and Upper Rx Antenna), L_{sys1}	142.8	dB	Item 16 + Item 8 + Item 12
18.	Transmitter Power, P_T	27	dBm	From system design documents, and text
19.	Thermal Noise per Hertz, KT_o	-174	dBm/Hz	$P_n = KT_o$
20.	Receiver Noise Figure, N_f	10	dB	From system documents or equipment specifications
21.	Receiver Noise Density, N_o	-164	dBm/Hz	Item 19 + Item 20
22.	Modulation Bit Rate, B_r	12.6×10^6	bits/sec	From system documentation
23.	10 $\log_{10}$ (Item 22)	71	dB	
24.	Required E_b/N_o for BER = 10^{-4}	16	dB	From Table A-III, or equipment specification (Equip. type AN/FRC-162)

EXAMPLE C-1
(TABLE A-I, Continued)

25.	Threshold (faded RSL), RSL_f	-77 dBm	Item 21 + Item 23 + Item 24 or from equipment specification
26.	Fade Margin Required, M_f	27.4 dB	Item 2 < 32 km, use: $M_F = 20 \log (\text{Item } 2) + 2$ Item 2 > 32 km, use: $M_F = 9 \log (\text{Item } 2) + 18$
27.	Fade Margin Correction Factor	0 dB	See text and Table A-IV
28.	Corrected Fade Margin, M_{fc}	27.4 dB	Item 26 + Item 27
29.	Implementation Loss Margin	6 dB	See text.
30.	Total Link Margin, M_L	33.4 dB	Item 28 + Item 29
31.	Total Antenna Gain Required (both ends), $2G_A$	72.2 dB	Item 25 + Item 30 + Item 17 - Item 18
32.	Required Antenna Diameter, D	1.22 m	See text and Table A-V.

EXAMPLE C-1

TABLE B-I

DETERMINATION OF
FADE OUTAGE PROBABILITY PER CALL MINUTE

(5 sec < FOD < 60 sec)

(NOTE: Items previous to 33 are found in Table A-I).

33.	Single Antenna Gain	37.3 dBi	Item 14 + 20 log (Item 32) + 17.52, or from Table A-V, or from manufactures data.
34.	Unfaded RSL, RSL_{uf}	-41.2 dBm	Item 18 + 2 x (Item 33) - Item 17
35.	Actual Fade Margin, M_{fa}	29.8 dB	Item 34 - Item 25 - 6
36.	Average Yearly Temperature, T_{ave}	50 ^oF	Area Weather Bureau (See text)
37.	Portion of the Year that Constitutes the Fading Season, a	0.25	0.005 x (Item 36) or from Figure B-I
38.	Terrain Roughness Factor, W	15 m	From path profile, and see text.

6 m, smooth earth
W = 15 m, average earth
42 m, rough earth

39.	Item 38 ÷ 15	1
40.	$(\text{Item } 39)^{-1.3}$	1
41.	Climate Factor, K	1

2, humid (coastal)
K = 1, average
0.5, dry

EXAMPLE C-1

(TABLE B-1, Continued)

42.	Climate and Terrain Factor, C	1	Item 41 x Item 40, or from Figure B-II text
43.	Diversity Switch	2.51	$r^2 = \log^{-1}\boxed{\frac{R}{10}}$ where R = hysteresis in dB, if R is unknown use $r^2 = 2.51$
44.	Item 43 + (1 ÷ Item 43)	2.91	See text.
45.	0.149 x $(\text{Item } 2)^4$	18220	
46.	Item 35 ÷ 5	5.96	
47.	$10^{-(\text{Item } 46)}$	1.0965×10^{-6}	
48.	Receive Antenna separation for space diversity system	9.14 m	From system documents or see text
	or		
	equivalent factor for frequency diversity system	-	See text for explanation.
49.	Diversity Factor	900	10.765 x $(\text{Item } 48)^2$
50.	56 x Item 49	50400	
51.	Item 44 x Item 37 x Item 42 x Item 45 x Item 47	1.453×10^{-2}	
52.	Probability RSL is below threshold P_o	2.882×10^{-7}	Item 51 ÷ Item 50
53.	$Z(M_F, D, f)$ factor	3.8	See text.

EXAMPLE C-1

(TABLE B-1, Continued)

54.	Probability of a fade outage with a duration between 5 seconds and 60 seconds	1.0952×10^{-6}	Item 53 x Item 52

To determine whether the above design meets the design criteria continue as follows.

55.	Item 2 x (2.6×10^{-7})	4.862×10^{-6}	
56.	Item 54 ÷ Item 55	0.23	(Should be less than 2.0)

57. If Item 56 is greater than 2.0 the recommended course of action is to increase system gain by employing one or more of the following, until a ratio of 2.0 or less in Item 56 above is obtained.

   a. Increase antenna size

   b. Increase transmitter power

   c. Use lower loss transmission line

   d. Use lower noise receiver

   e. Separate space diversity antennas (max. 15 meters)

   f. Use higher order of diversity.

EXAMPLE C-2

TABLE A-I
DIGITAL LOS PATH CALCULATION PROCEDURE

LOS Path: CDF to PDO

1.	Frequency, f	1.85 GHz	From system plan
2.	Path Length, d	106.4 km	From map study or site records
3.	Transmitter Antenna Height above ground	27.6 m	From site records or path profile
4.	Transmitter Horizontal Transmission Line Length	2.4 m	From site records
5.	Total Tx Transmission Line Length	30 m	Item 3 + Item 4
6.	Transmission Line Type: rectangular (WR-430), elliptical ( ), circular ( ), coaxial ( ),	WG	Transmission line selected for use on the system.
7.	Transmission Line Loss Factor	0.015 dB/m	For particular waveguide in use (See Table A-II) or manufacturer data).
8.	Total Tx Transmission Line Loss	0.45 dB	Item 7 x Item 5
9.	Receiving Antenna Height above ground (Upper antenna if space diversity is used)	20 m	From site records or path profile
10.	Receiving Horizontal Transmission Line Length	10 m	From site records
11.	Total Receiving Transmission Line Length	30 m	Item 9 + Item 10
12.	Total Rx Transmission Line Loss	0.45 dB	Item 7 x Item 11

EXAMPLE C-2

(TABLE A-I, Continued)

13.	Lower Receiving Antenna Height above ground (If space diversity is used)	10 m	From site records or path profile. The antenna spacing is 9.1 meters. (Item 48 in Appendix B).
14.	20 $\log_{10}$ (Item 1)	5.34 dB	
15.	20 $\log_{10}$ (Item 2)	40.54 dB	
16.	LOS Free Space Loss (median), L_{fs}	138.4 dB	Item 15 + Item 14 + 92.5
17.	Total Losses (Tx and Upper Rx Antenna), L_{sys1}	139.3 dB	Item 16 + Item 8 + Item 12
18.	Transmitter Power, P_T	33 dBm	From system design documents, and text
19.	Thermal Noise per Hertz, KT_o	-174 dBm /Hz	$P_n = KT_o$
20.	Receiver Noise Figure, N_f	2.5 dB	From system documents or equipment specifications
21.	Receiver Noise Density, N_o	-171.5 dBm/Hz	Item 19 + Item 20
22.	Modulation Bit Rate, B_r	6.3×10^6 bits/sec	From system documentation
23.	10 $\log_{10}$ (Item 22)	68 dB	
24.	Required E_b/N_o for BER = 10^{-4}	11.8 dB	From Table A-III, or equipment specification (Equip. type Digital Radio "x"

EXAMPLE C-2
(TABLE A-I, Continued)

25.	Threshold (faded RSL), RSL_f	-91.7 dBm	Item 21 + Item 23 + Item 24 or from equipment specification
26.	Fade Margin Required, M_f	36.2 dB	if Item 2 < 32 km, use: M_F = 20 log (Item 2) + 2 if Item 2 > 32 km, use: M_F = 9 log (Item 2) + 18
27.	Fade Margin Correction Factor	+4.1 dB	See text and Table A-IV
28.	Corrected Fade Margin, M_{fc}	40.3 dB	Item 26 + Item 27
29.	Implementation Loss Margin	6 dB	See text.
30.	Total Link Margin, M_L	46.3 dB	Item 28 + Item 29
31.	Total Antenna Gain Required (both ends), $2G_A$	60.9 dB	Item 25 + Item 30 + Item 17 - Item 18
32.	Required Antenna Diameter, D	3.05 m	See text and Table A-V

EXAMPLE C-2

TABLE B-I

DETERMINATION OF
FADE OUTAGE PROBABILITY PER CALL MINUTE

(5 sec < FOD < 60 sec)

(NOTE: Items previous to 33 are found in Appendix A).

33.	Single Antenna Gain	33.3 dBi	Item 14 + 20 log (Item 32) + 17.52, or from Table A-V, or from manufacturer's data.
34.	Unfaded RSL, RSL_{uf}	-39.7 dBm	Item 18 + 2 x (Item 33) - Item 17
35.	Actual Fade Margin, M_{fa}	46 dB	Item 34 - Item 25 - 6
36.	Average Yearly Temperature, T_{ave}	78 °F	Area Weather Bureau (See text)
37.	Portion of the Year that Constitutes the Fading Season, a	0.39	0.005 x (Item 36) or from Figure B-I
38.	Terrain Roughness Factor, W	6 m	From path profile, and see text

$$W = \begin{cases} 6 \text{ m, smooth earth} \\ 15 \text{ m, average earth} \\ 42 \text{ m, rough earth} \end{cases}$$

39.	Item 38 ÷ 15	0.4
40.	$(\text{Item } 39)^{-1.3}$	3.29
41.	Climate Factor, K	2

$$K = \begin{cases} 2\text{, humid (coastal)} \\ 1\text{, average} \\ 0.5\text{, dry} \end{cases}$$

EXAMPLE C-2

(TABLE B-II, Continued)

42.	Climate and Terrain Factor, C	6.58	Item 41 x Item 40, or from Figure B-II text
43.	Diversity Switch	2.51	$r^2 = \log^{-1}\left[\frac{R}{10}\right]$ where R = hysteresis in dB, if R is unknown use $r^2 = 2.51$
44.	Item 43 + (1 ÷ Item 43)	2.91	See text.
45.	0.149 x $(\text{Item } 2)^4$	19096460	
46.	Item 35 ÷ 5	9.20	
47.	$10^{-(\text{Item } 46)}$	6.31×10^{-10}	
48.	Receive Antenna separation for space diversity system	9.14 m	from system documents or see text
	or		
	equivalent factor for frequency diversity system	______	See text for explanation.
49.	Diversity Factor	900	10.765 x $(\text{Item } 48)^2$
50.	56 x Item 49	50400	
51.	Item 44 x Item 37 x Item 42 x Item 45 x Item 47	9×10^{-2}	
52.	Probability RSL is below threshold P_o	1.785×10^{-6}	Item 51 ÷ Item 50
53.	$Z(M_F, D, f)$ factor	3.5	See text.

EXAMPLE C-2

(TABLE B-I, Continued)

54. Probability of a fade outage with a duration between 5 seconds and 60 seconds	6.427×10^{-6}	**Item 53 x Item 52**

To determine whether the above design meets the design criteria continue as follows.

55. Item 2 x (2.6×10^{-7})	2.766×10^{-5}	
56. Item 54 ÷ Item 55	0.23 (Note 1)	(Should be less than 2.0)

57. If Item 56 is greater than 2.0, the recommended course of action is to increase the system gain by performing one or more of the following, until a ratio of 2.0 or less in Item 56 above is obtained.

a. Increase antenna size

b. Increase transmitter power

c. Use lower loss transmission line

d. Use lower noise receiver

e. Separate space diversity antennas (max. 15 meters)

f. Use higher order of diversity.

NOTE 1: The first iteration produced an antenna diameter of 2.44 meters with an Item 56 value of 3.47. Increasing the antenna diameter by one standard size, a system was produced which exceeded the DCEC TR 12-76 design objective.

APPENDIX D

SIMPLIFIED PROCEDURE FOR DETERMINING REQUIRED LINK MARGIN AND ANTENNA SIZE FOR DCS LOS DIGITAL LINKS

1. INTRODUCTION

Appendixes A and B provide detailed procedures for calculating and verifying parameters for DCS LOS links to meet system performance and availability criteria established in DCEC TR 12-76. These procedures are relatively time-consuming and require detailed topographic, climatological, equipment and station layout information. One recognizes that there will be many instances in which a quick-reaction desk top system design is required for planning projections in which only sketchy information is available. The procedure presented in this appendix will serve the purpose in these instances and is quite accurate unless the prevailing path conditions and equipment characteristics depart substantially from the ones assumed (as stated in the procedures). The nomographs developed in this appendix will permit the user to quickly determine the required link margin and antenna size for an LOS link to meet the performance and availability criteria established in DCEC TR 12-76.

2. ASSUMPTIONS

The development of the nomographs shown in Figures D-1 through D-4 was based on the set of conditions and equipment characteristics given in Tables D-I and D-II.

TABLE D-I

LIST OF ASSUMPTIONS USED IN DEVELOPING THE NOMOGRAPHS, FIGURES D-1 THROUGH D-4

PARAMETER	FREQUENCY BAND	
	4 GHz	8 GHz
1. Waveguide loss (ellipical) (assumed 100 foot antenna heights and 50 foot horizontal run on each end.)	3 dB	7.5 dB
2. RF Equipment	SEE TABLE D-II	
3. System Gain	DETERMINED AT BER LEVEL OF 10^{-4}	
4. Diversity	DUAL (FREQUENCY OR SPACE)	
5. Climate Terrain Temperature	AVERAGE CONDITIONS	

TABLE D-II
EQUIPMENT CHARACTERISTICS

LOS DIGITAL RADIO TYPES	FREQUENCY BAND (GHz)	MAXIMUM EQUIVALENT VOICE CHANNELS	SYSTEM GAIN (dB)	FIGURE TO BE USED (FIGURE NUMBER)
AN/FRC-169*	4	192	104	D-I
AN/FRC-162*	8	192	104	D-II
AN/FRC-( )*	4	192	114	D-III
AN/FRC-165*	8	192	114	D-IV
DRAMA (1 b/Hz)	4	192	104	D-I
DRAMA (1 b/Hz)	8	192	104	D-II
DRAMA (2 b/Hz)	4	384	104	D-I
DRAMA (2 b/Hz)	8	384	104	D-II

*Modified Standard FM Radio

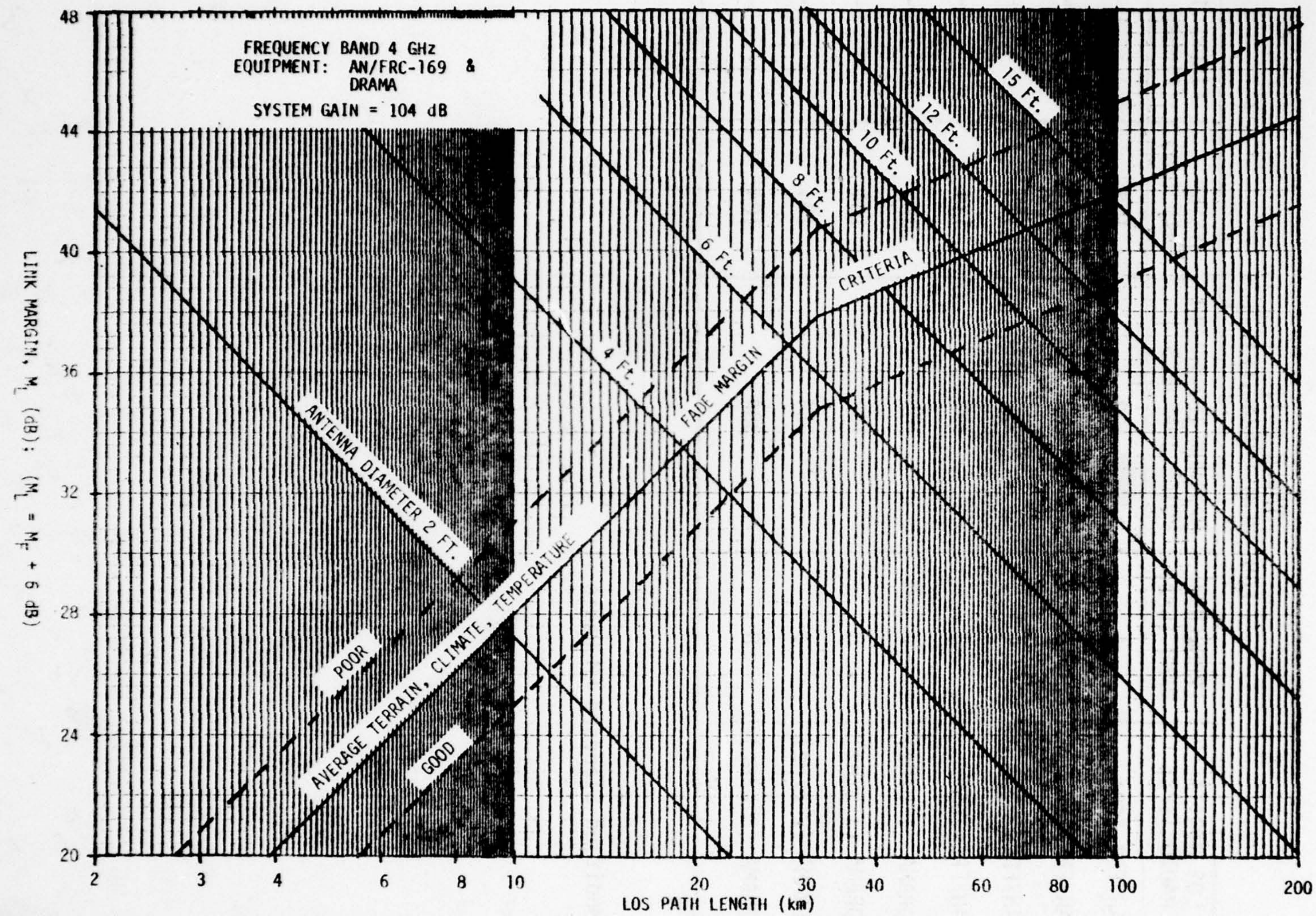

Figure D-1. Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links

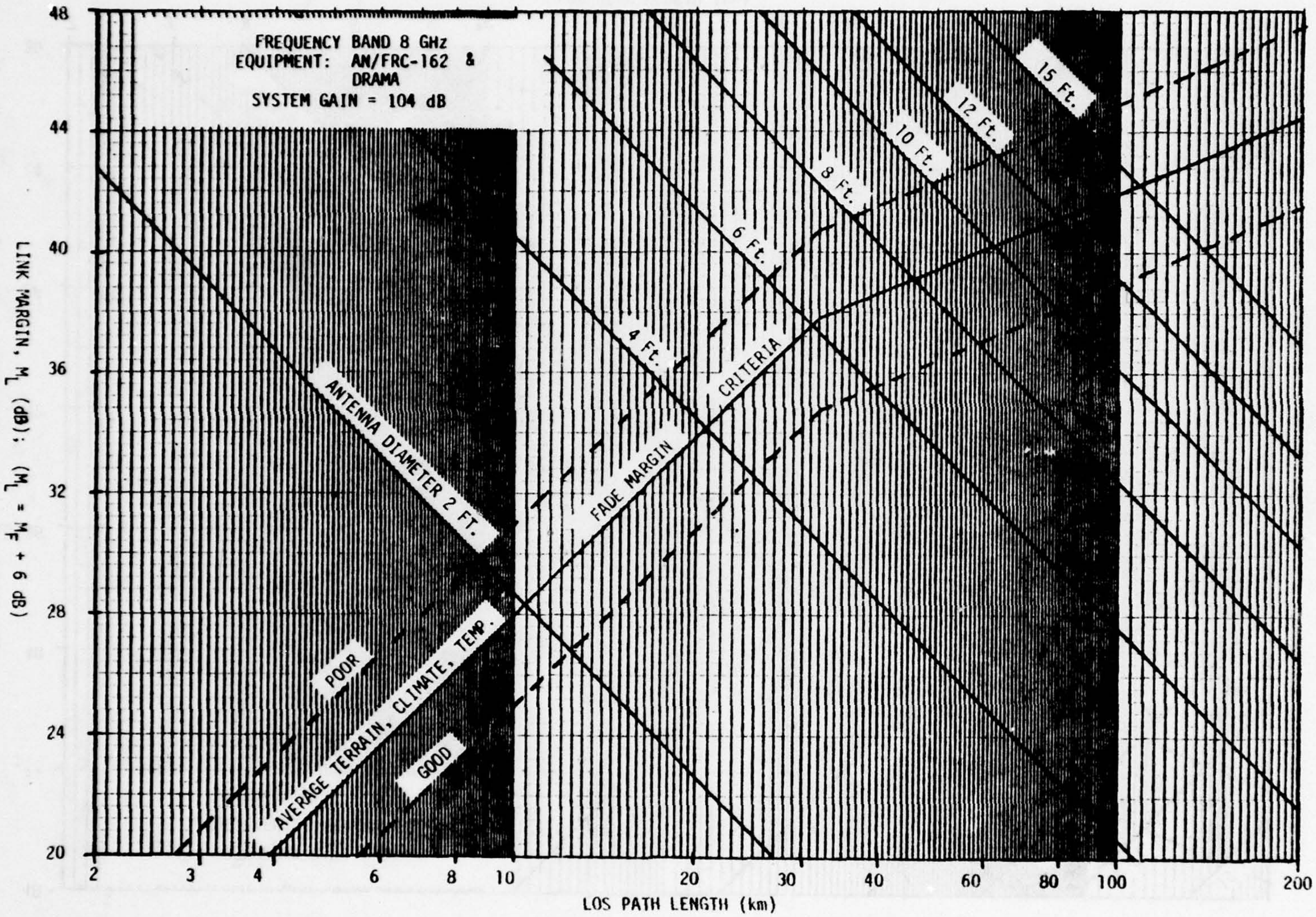

Figure D- 2 Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links

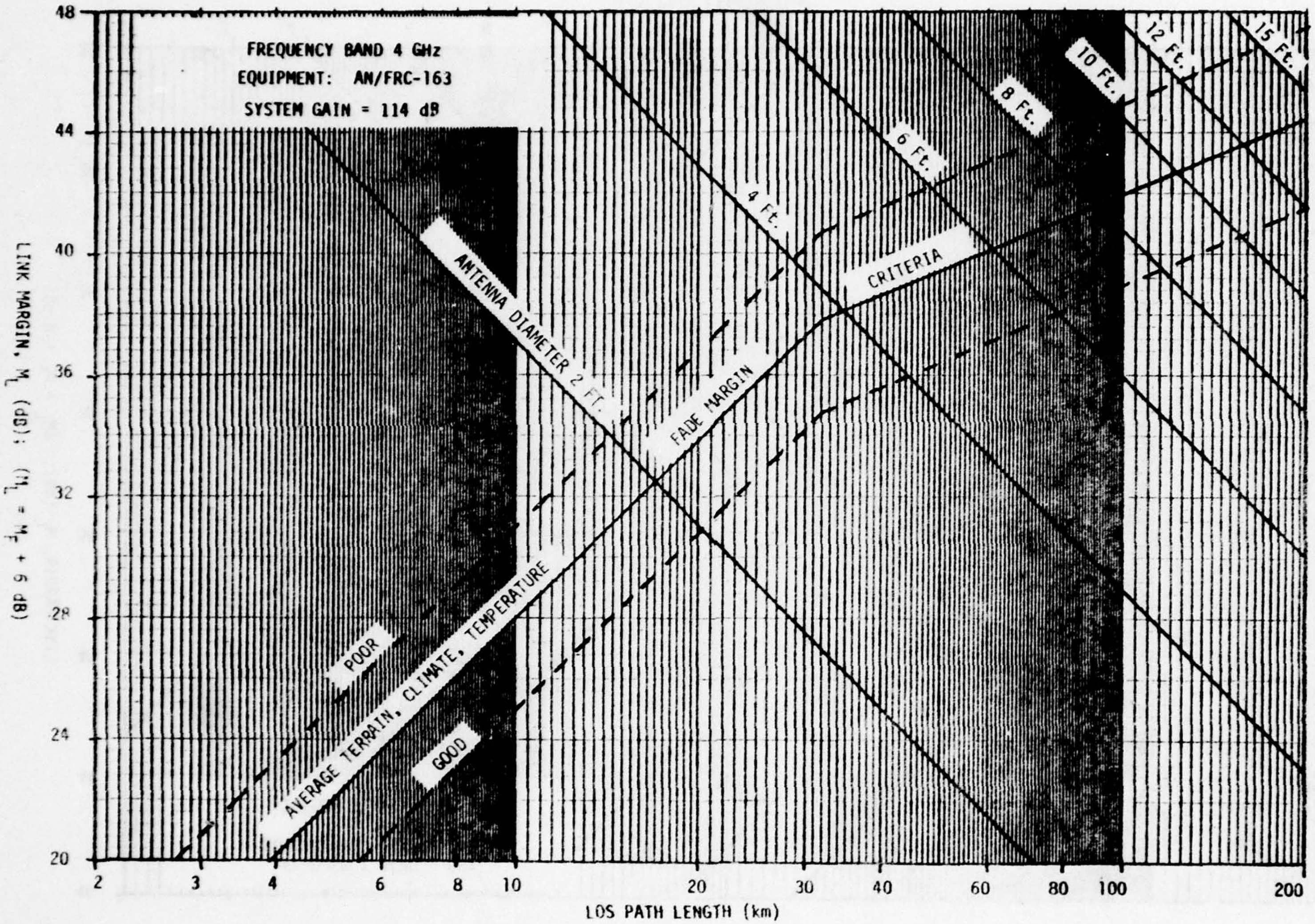

Figure D-3. Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links

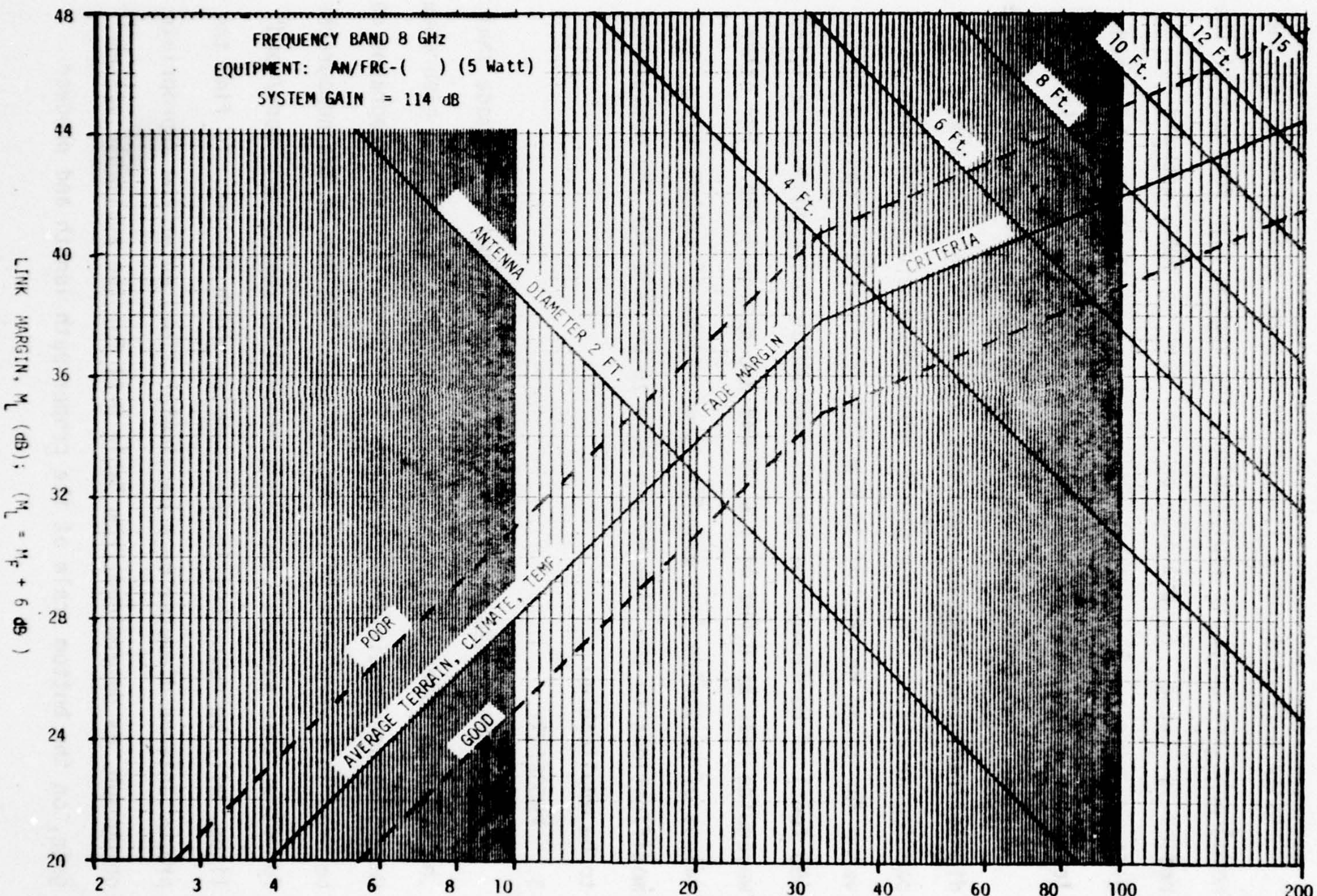

Figure D-4. Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links

Table D-II contains a list of LOS digital radios for which the nomographs are directly applicable. The system gain for each of the radios is stated. System gain as used here is the algebraic difference of the transmitter power output and the E_b/N_o threshold level for a bit error probability of 10^{-4}, both quantities in dBm.

These nomographs, Figures D-1 through D-4, can be used for other digital radios as long as one knows the system gain for that particular radio. The nomographs were prepared using an average value for tower heights of 30.5 m (100 feet) at each end and 15.3 m (50 feet) of horizontal waveguide runs which corresponds to a total waveguide loss at 8 GHz of 7.5 dB and 3.0 dB for 4 GHz. For other values of waveguide loss and for other values of system gain, modifications to the link margin have to be made for the nomographs to be applicable.

3. PROCEDURE

As in the procedure of Appendix A, the assumption is made that the LOS path under consideration will have the proper path clearance. Under average conditions (as stated in Table D-I), the nomographs can be used in a very straightforward manner. The use of the nomographs for other than average conditions, including the dotted "poor/good" lines, will be described in the examples which follow. To find the proper antenna diameter on a particular link, enter the appropriate nomograph, as determined from Table D-II for the available system gain, on the bottom scale at the proper path length and proceed

vertically up the chart until the solid "knee bend" line, representing the fade margin criteria, is intersected. At this intersection, the required link margin (M_L) is read from the left hand scale. This link margin is the minimum value required to meet the fade outage probability criterion established in DCEC TR 12-76. The required antenna diameter is determined from the intersection of the diagonal antenna diameter lines with the fade margin criteria line. The minimum antenna diameter is the one which will either meet or just exceed the required link margin.

4. USE OF THE NOMOGRAPHS FOR OTHER THAN THE ASSUMED CONDITIONS

The use of the nomographs (Figures D-1 through D-4) for other than the assumed conditions (Table D-I and D-II) will be illustrated by means of several examples:

Example 1:	Path Distance:	50 km (31.1 miles)
	Radio:	AN/FRC-162
	Total Waveguide Losses:	5.5 dB

From Table D-I, the use of the nomograph of Figure D-2 is indicated as shown in Figure D-5. The following procedure, as outlined in paragraph 3, gives the required link margin of 39.5 dB (Point 1) for the assumed average conditions. In this case, however, the total waveguide loss is only 5.5 dB; 2.0 dB lower than assumed average. Hence, the required link margin should be lowered by 2.0 dB (Figure D-5, Point 2) and the required antenna diameter is only 8 ft rather than 10 ft.

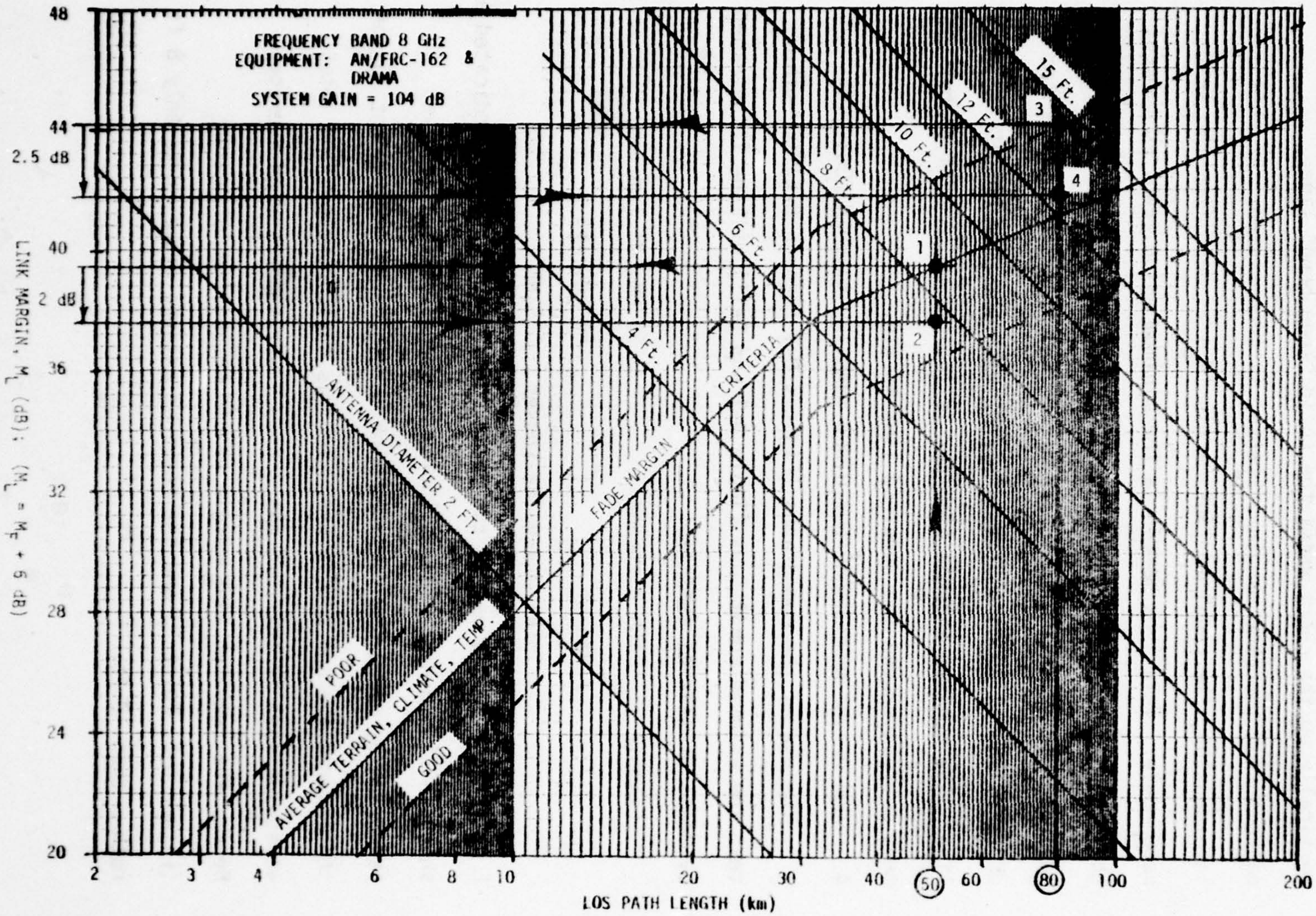

Figure D-5. Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links (Examples 1 and 2)

Example 2:	Path Length:	80 km (50 miles)
	Radio:	AN/FRC-162
	Total Waveguide Losses:	5.0 dB
	Over water path	

Figure D-5 is used for this example. Following the procedure outlined in the above paragraph 3 gives the required link margin of 44 dB. Since the path is over water and is considered "poor" for propagation conditions, the "poor" fade margin criterion line is used (Figure D-5, Point 3). In this case, however, the total waveguide loss is only 5.0 dB; 2.5 dB lower than assumed average. Hence, the required line margin should be lowered by 2.5 dB (Figure D-5, Point 4) and the required antenna diameter is only 12 feet rather than 15 ft.

Example 3:	Path Distance:	25 km (15.5 mile)
	Radio:	AN/FRC-XXX, (4 GHz)
	Total Waveguide Losses:	10.5 dB
	System Gain:	100 dB
	Equivalent VF:	192 channels

From Table D-I, notice that there is not a directly applicable nomograph, but Figure D-1 can be used. Following the procedure which is outlined in the above paragraph 3 gives the required link margin of 35.6 dB (Figure D-5, Point 1), for the assumed average conditions. In this case, however, the system gain is only 100 dB, which is 4 dB lower than the average system gain. Therefore, 4 dB has to be added to the link margin (Figure D-5, Point 2). Also, the

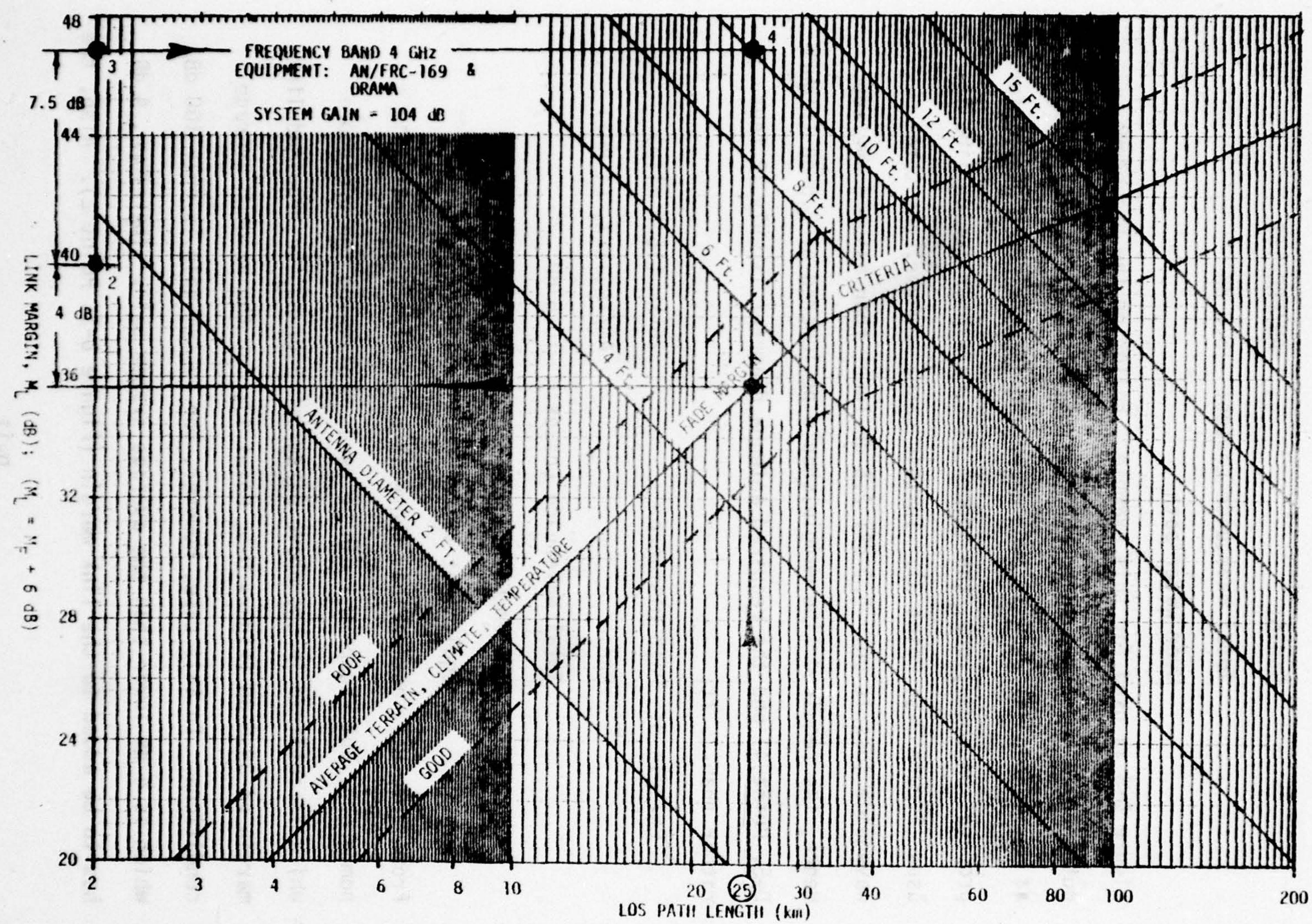

Figure D-6. Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links (Example 3)

total transmission line loss is 10.5 dB, which is 7.5 dB higher than the average transmission line loss. The additional transmission line loss brings the link margin requirement up to 47.1 dB (Figure D-5, Point 3). Hence, the required antenna diameter is 10 feet rather than 6 ft.

Example 4:	Path Distance:	161 km (100 mile)
	Radio:	DRAMA
	Total Waveguide Losses:	5.0 dB
	Over water	

From Table D-1, the use of the nomograph of Figure D-2 is indicated, as shown in Figure D-7. Again, following the procedure outlined in the above paragraph 3 gives the required link margin of 46.6 dB (Figure D-5, Point 1) for the assumed average conditions over water (i.e. "poor"). In this case, however, the total waveguide loss is 5.0 dB; 2.5 dB lower than the average waveguide loss. Hence, the required link margin should be lowered by 2.5 dB (Figure D-5, Point 2). As indicated, in order to meet or nearly meet the fade outage requirement for this link, 5 more dB of system gain would be required if antennas were restricted to 15 feet in diameter (Figure D-5, Point 3). This extra system gain can be accomplished through the employment of low noise preamplifiers, RF power amplifiers, or any other means which is most cost effective.

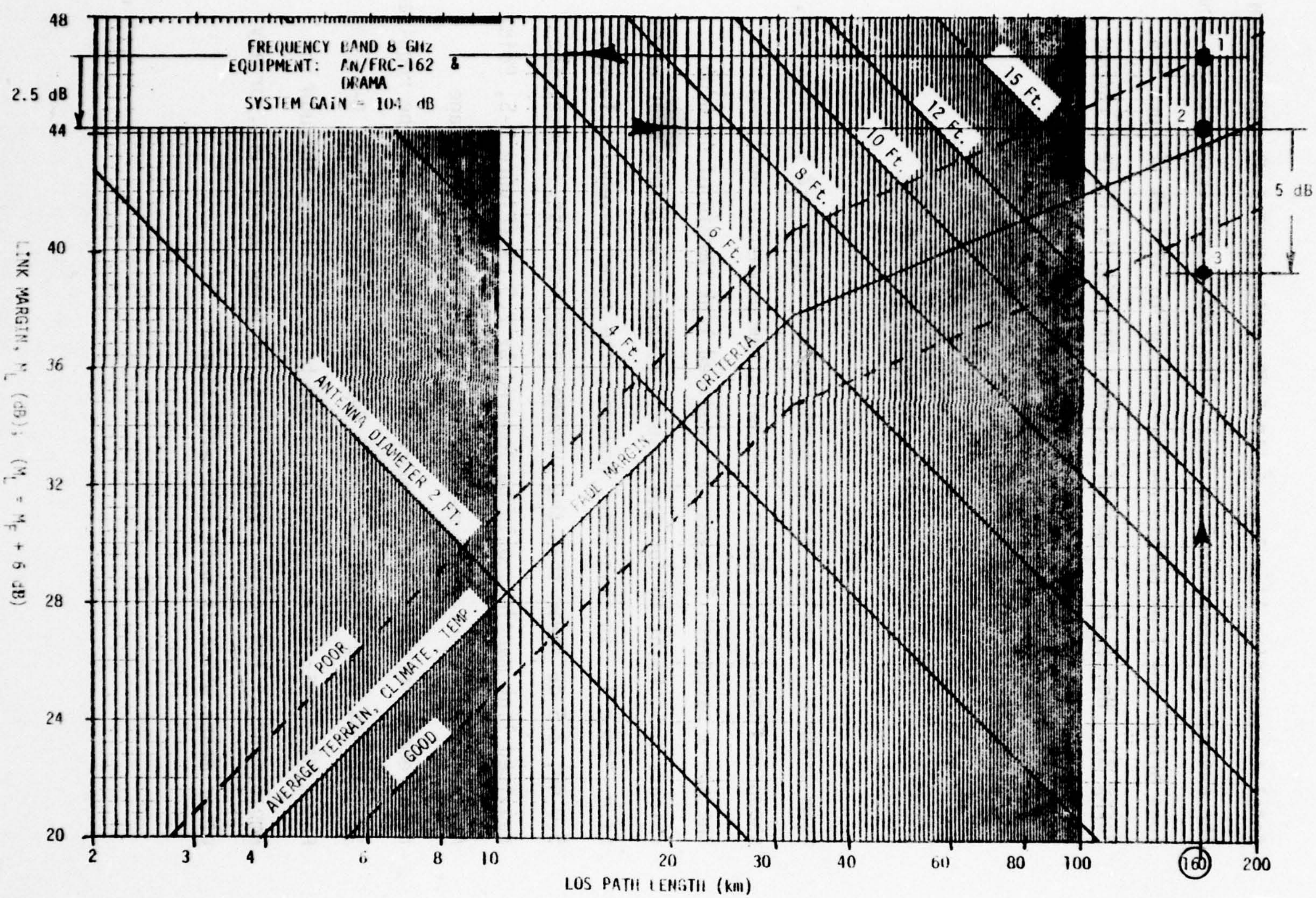

Figure D-7. Nomograph for Determining Link Margin and Antenna Diameter for Digital LOS Links (Example 4)

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